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Magnetite Deposits of French Creek, Pennsylvania

By

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James F. Woodward, *Secretary*

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LETTER OF TRANSMITTAL

James F. Woodward, Secretary,

Department of Internal Affairs.

Sir:

Geologists study ore deposits for much the same reasons that a surgeon explores the human body. It is only as we determine the shape and size of an ore body, its relation to the enclosing rocks, its character as revealed in the microscope and chemical laboratory, that we can understand its origin and history and thus know where to look for other deposits, or how to judge their possible extent or value. In this study Mr. Smith was fortunate in being able to return to the mine just as the last of the ore was being removed. His drawings, therefore, disclose the full extent of the ore body and make possible a more complete description than usual.

Ore bodies of similar origin have furnished almost all of the iron mined in Pennsylvania in the last half century. It is hoped that many similar unknown deposits exist in the State and that this paper may be a help in finding them and in judging their value if found.

Respectfully submitted,

Geo. H. Ashley

State Geologist.

April 21, 1930.

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THE MAGNETITE DEPOSITS OF FRENCH CREEK, PENNA.

By Laurence L. Smith

LOCATION AND HISTORY

The French Creek mines are located at Saint Peters, a small village in the extreme northern part of Chester County, Pa., at the terminus of the Saint Peters branch of the Philadelphia & Reading Railroad. The village lies 14 miles southeast of Reading, 7 miles southeast of Birdsboro, and 6 miles southwest of Pottstown. All of these cities are situated on Schuylkill River, and are important centers in the iron and steel industry.

The iron mines of this region are among the oldest in the United States, some of them having been important producers for the Colonial armies during the Revolutionary war. In the Records of the Historical Society of Chester County, Mr. Cyrus Fox has described many interesting incidents regarding the early history of the Jones, Warwick, and other mines of this region. But little, however, is known regarding the early development of the French Creek mines though they are said to have been operated at least one hundred years ago.

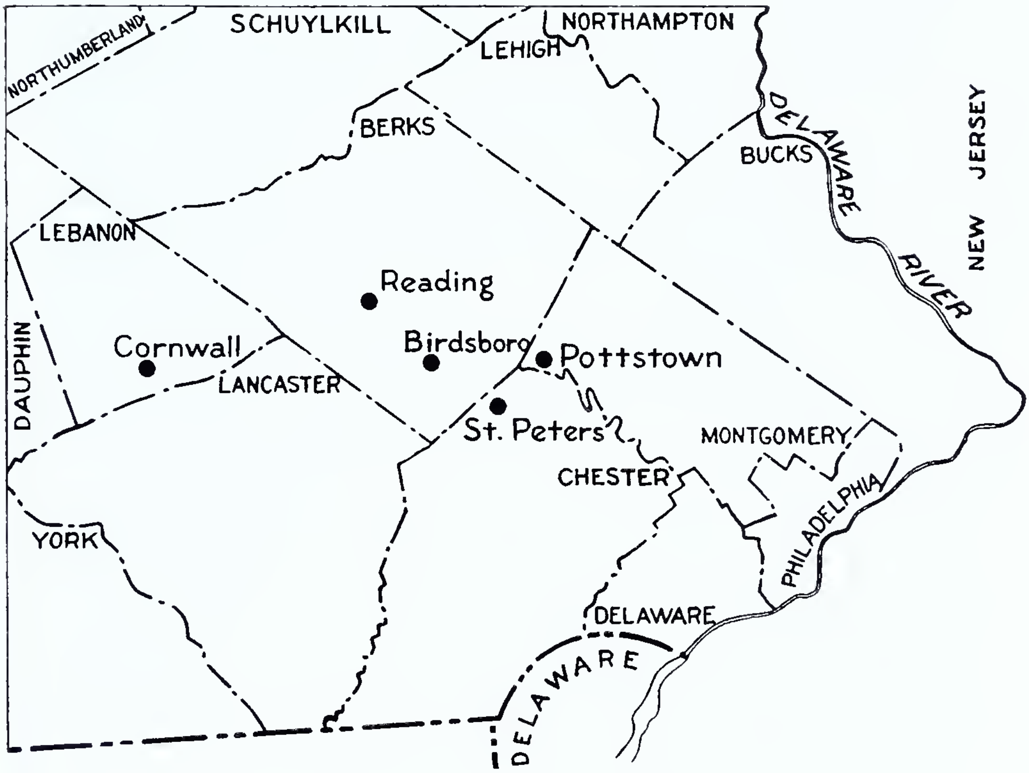

Figure 1. Map of southeastern Pennsylvania showing location of Saint Peters.

H. D. Rogers[1] gives a brief description of two mines which were opened up on the lode which later was worked as the French Creek Mine No. 1. The Crossley iron-ore pits which he described are evidently the series of pits still seen along the strike of this deposit. Rogers states that prosecution of operations had been suspended some years before his writing (1854), though evidently some ore had been extracted. He further describes a small experimental copper mine known as the Elizabeth Copper Mine immediately adjoining the Crossley iron-ore pits and apparently on the same vein. The mine never produced any copper and active operations were suspended in 1854. A shaft had been sunk to a depth of 145 feet, and this shaft was probably the one later used when this deposit was mined for iron.

The first mention of the French Creek Mine No. 2, which is here to be described, was by J. P. Lesley.[2] The mine at that time (1882) was operated conjointly by the E. & G. Brooke Iron and Steel Co. and the Phoenix Iron Co., and was producing about 15,000 tons of ore annually.

The dumps from the French Creek mines have long been a favorite rendezvous for mineral collectors because of the beautiful specimens of apophyllite, iron pyrites, and byssolite (an olive-green fibrous variety of amphibole asbestos) found there.

The geologic work on which this report is based was originally undertaken with the purpose of possibly shedding some additional light upon the magnetite deposits of southeastern Pennsylvania commonly known as the Cornwall type, which have been described in considerable detail by A. C. Spencer.[3]

This group of deposits lies in that portion of the Piedmont region of Pennsylvania extending from Boyertown southwestward to Dillsburg. It comprises the once important mines of Boyertown; the Wheatfield and Fritz Island groups just south and southwest of Reading; the Jones, Warwick, and Hopewell mines several miles south of the Reading group; and the Dillsburg group near Harrisburg. The belt including these variously scattered deposits is about 75 miles long, and from 5 to 20 miles wide, which corresponds to the width of the Piedmont in this locality.

These magnetic deposits have the common feature of being replacements of limestone, and these replacements are all located at or near the contact of Triassic intrusions which generally are diabase or closely allied rocks. The limestone which was replaced by magnetite is usually some member of the Cambro-Ordovician series. However, in some places deposits occur as replacements of calcareous beds in the Triassic sedimentaries. Thus, the outstanding characteristics which these deposits have in common are: (1) They are replacements of calcareous beds and, (2) they lie in close proximity to Triassic intrusions generally of the nature of diabase.

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[1] First Geol. Survey of Pa., vol. 2, part 2, 1858.

[2] Second Geol. Survey of Pa., vol. C4, pp. 244, 1883.

[3] Spencer, Arthur C., Magnetite deposits of the Cornwall type in Pennsylvania: U. S. Geol. Survey Bull. No. 359, 1908.

In the course of the field work of which this paper is the result, it was found that the magnetite deposits at French Creek and at the now abandoned Hopewell mine 1½ miles due west from French Creek exhibit these essential characteristics of the so-called "Cornwall type" and should be considered as such.

Of all the deposits which helped to make Pennsylvania at one time the largest iron-producing State in the Union and which initiated the establishment of the steel industry in eastern Pennsylvania, only two were being worked in 1928. The Cornwall deposit just south of Lebanon, Pa., operated by the Bethlehem Steel Company, is the largest iron mine in the State. The other, the French Creek mine at Saint Peters, operated by the E. & G. Brooke Iron and Steel Company, is the second largest producing mine. The normal annual output of this mine is about 100,000 tons of magnetite iron ore. Since the completion of the major part of the work on the French Creek deposit by the author in 1924, there has been a steady decline in production until the fall of 1928 when the mine was closed because the ore was exhausted.

ACKNOWLEDGMENTS

The writer welcomes this opportunity to express his appreciation to those who have assisted, both directly and indirectly, in making this work possible. In the geological faculty of Johns Hopkins University he has always found a constant source of encouragement and inspiration. Prof. Edward B. Mathews has also kindly assisted in the determination of the minerals and offered many helpful suggestions regarding the subject matter of this paper.

M. T. Hoster and James Burke, respectively superintendent and mining engineer of the French Creek mines, assisted in facilitating the field work; and the late Prof. F. B. Peck of Lafayette College, to whom the writer owes his earlier interest in the science of geology, accompanied him on several field trips and rendered helpful advice in conjunction with this work.

PHYSIOGRAPHY AND TOPOGRAPHY

Only a brief summary need here be given of the physiography of this region, which is typical of the Piedmont area in general. The southwestward extension of the New Jersey Highlands into Pennsylvania is known as the Durham and Reading Hills which form the northern boundary of the Piedmont region to Reading where the tip of this prong of hills is broken across by Schuylkill River. Shortly beyond this point the highland area descends to the general level of the Piedmont which then merges into the Lebanon Valley; but farther to the southwest the Highlands are continued by the South Mountains which again gives the Piedmont a more distinct boundary on the northwest.

On the southeast the Piedmont is bordered rather indefinitely by the Coastal Plain forming an irregular line that extends from Trenton, New Jersey southwestward via Philadelphia and Wilmington, across the Pennsylvania-Delaware line and into Maryland.

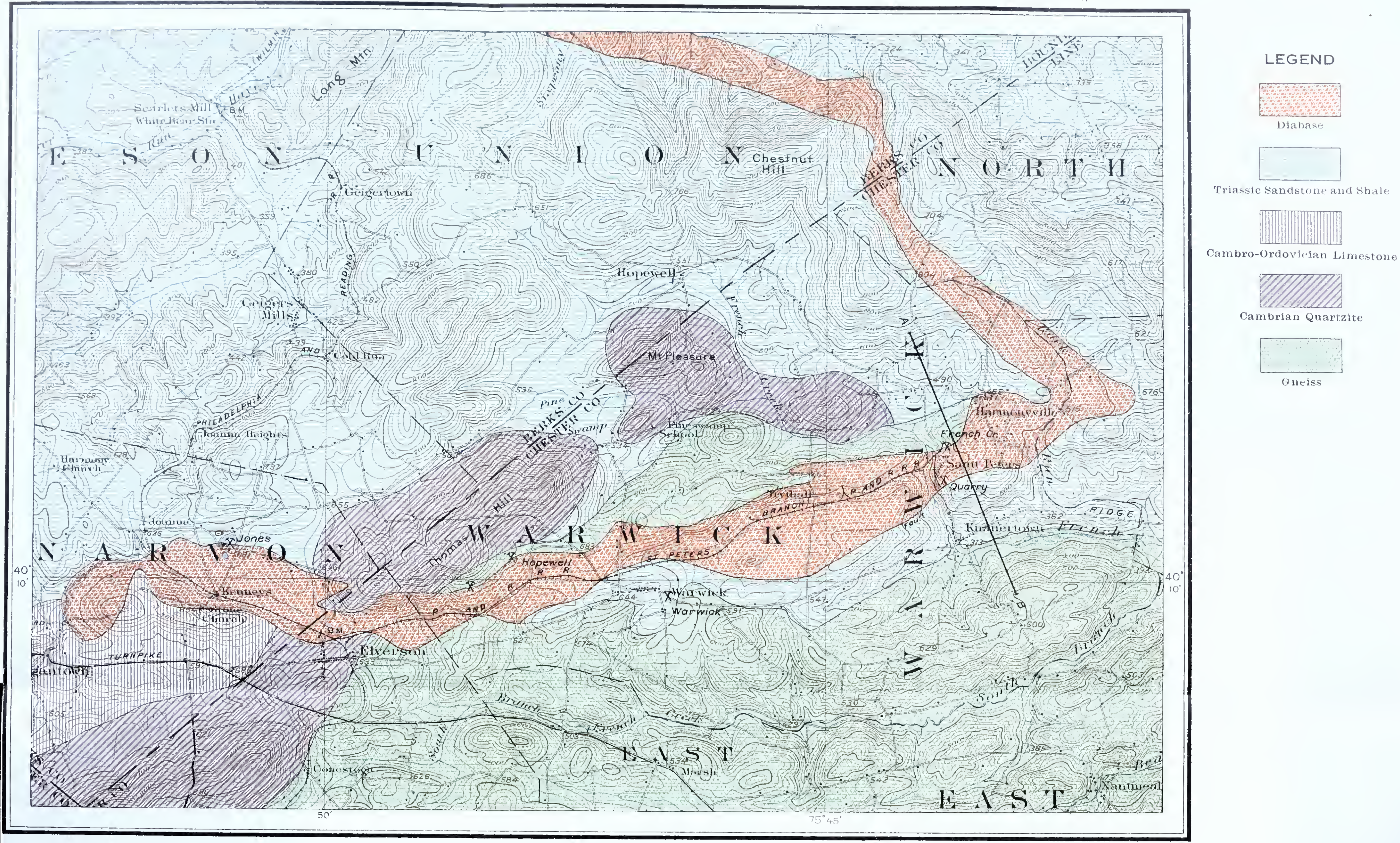
In the French Creek locality, the plateau is dissected by mature stream systems into rounded hills and irregular intervening valleys. There is a difference in elevation of 400 to 500 feet between the summits of the hills and the floors of the valleys. The altitude of the highest hills is about 900 feet, from which there is a gradual decrease toward the south. One noticeable exception is Welsh Mountain with an altitude of 1000 feet. It rises about 8 miles west of Saint Peters and extends southwest for 15 miles.

From this immediate vicinity, the drainage pursues three different courses. It may flow northward into the Schuylkill by way of a number of short streams. Just southeast of Reading several of these streams cut across a long narrow area of intrusive rocks, and consequently have here developed distinctly steep-sided valleys. Some streams, like French Creek, pursue a general southeasterly course for some distance, paralleling the direction of the Schuylkill River into which they eventually empty. Some of the drainage takes a more directly southern course by way of Brandywine Creek which flows into the Delaware at Wilmington, Del. Conestoga Creek also carries some of the drainage southwestward into the Susquehanna.

With the exception of the southwest flowing streams, there is no conformity between drainage and the general rock structure. A good example of this lack of conformity is seen at Saint Peters where French Creek cuts directly across a ridge composed of diabase.

GENERAL GEOLOGY

The Triassic red shales wrap around the outlying ridges of the Durham and Reading Hills and form a blanket stretching southward for varying distances over the underlying pre-Cambrian and Paleozoic rocks of the Piedmont. The accompanying map (Plate I) of the extreme northwestern corner of the Phoenixville and the northeastern portion of the Honeybrook quadrangle shows the French Creek locality situated at the southern boundary of the Triassic sediments. To the north there is an unbroken stretch of red shales to the Durham and Reading Hills except for the Triassic intrusions which locally cut through the shales. Southward as far as Chester Valley, a distance of 15 miles from Saint Peters, one encounters only pre-Cambrian gneisses and schists. In this long narrow valley Lower Cambrian



Base from U. S. Geological Survey

A. Hoen & Co Baltimore Md.

GEOLOGIC MAP SHOWING MAGNETITE DEPOSITS NEAR SAINT PETERS, CHESTER COUNTY, PA.

By Laurence L. Smith

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

1924

quartzites and schists and Cambro-Ordovician dolomites and limestones are exposed.

Westward from Saint Peters, the southern border of the Triassic shales is largely in contact with the lower Paleozoic sedimentaries which are exposed in Welsh Mountain and the surrounding valley.

A subordinate area of gneiss is cut off at the surface from the larger gneiss area to the south by a long lenticular mass of diabase and an intervening tongue of Triassic shale. This diabase mass extends westward from St. Peters for a distance of 9 miles, and varies from 500 yards to a mile in width. On the north it is in contact with the smaller gneiss area for most of its length. One mile east of Saint Peters, this diabase mass turns abruptly northwest across the red shale area to Reading. Its extreme western extension is in contact with lower Paleozoic quartzites and limestones both along the northern and southern boundaries.

Economically, this long narrow strip of igneous rock is of considerable importance for at or near its contact and genetically related to it are four deposits of iron ore, each of which has been a large producer. At the western extremity is the once famous Jones mine. About three miles east along the northern contact is the abandoned Hopewell mine and several small workings near by. A mile southeast of the Hopewell mine at Warwick village is another abandoned mine, the Warwick, which was also at one time a large producer of ore. And along the northern contact within a mile of the eastern extremity of the exposed portion of this diabase intrusion is located the French Creek mine at Saint Peters.

GENERAL STRUCTURE

There are practically no outcrops in this immediate region so that the geological mapping had to be done almost entirely from observation and study of the surface fragments. Neither is there any relationship between the areal distribution of the formations and the topography or drainage. With these difficulties to encounter, it is to be expected that the contacts as mapped may in places be only approximately accurate.

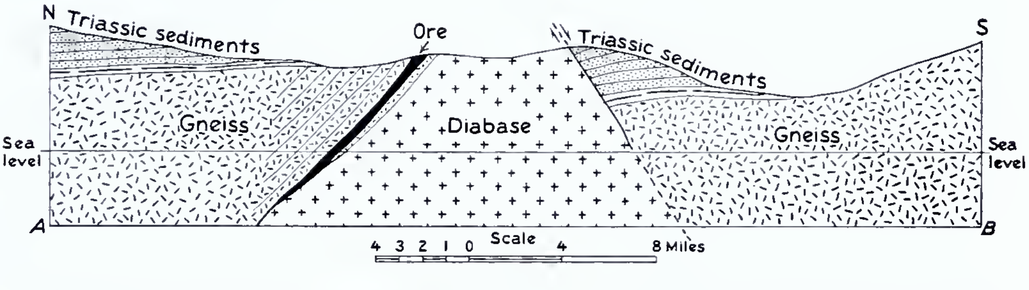


Figure 2. Geologic cross section at French Creek mine, Saint Peters, along line A-B on Plate I.

At Saint Peters, the north branch of French Creek has cut diagonally across the gneiss, sandstone and shale, and diabase formations and with the information here gained, together with artificial exposures, it has been possible to arrive at some conclusions regarding the relations and structures of the formations. The cross-section, Figure 2, constructed along line A—B of the geological map shows that the gneiss forms a basement on which has been deposited the Triassic sandstones and shales and through which the diabase has been intruded.

The gneiss as observed in the French Creek mine has an average strike of approximately east and west and a dip of 45° N. An outcrop in the bed of French Creek about a mile directly west has a similar strike and a nearly vertical dip.

The diabase is exposed in a large quarry in the village of Saint Peters, and about 60 yards from the south corner of the quarry the Triassic beds are well exposed by excavations along the highway leading to Knauertown. The sandstone and shale beds here display undoubted evidence of contact action which will be described later. They strike N. 70°E. parallel with their contact with the diabase, and dip 20°N. A small outcrop of red shale in a stream bed northwest of Harmonyville near the gneiss contact showed a dip of about 5°N. which is the average dip of this formation northward to Schuylkill River. Similar red shale is exposed south of Knauertown along French Creek and near its contact with the gneiss. But this exposure is at an elevation 200 feet lower than the former.

The above facts seem to indicate the presence of a fault along the south contact of the diabase intrusion, with a downthrow of about 200 feet on the south side and a tilting of about 15° toward the north.

The above facts may also be explained by assuming that the original surface on which the Triassic deposits were laid down was very irregular, that there were intervening monadnocks around which deposition took place, and that there was a tilting of the strata to the north previous to the intrusion of the diabase.

The general direction of strike of the gneiss-diabase contact along the north border of the diabase tends to conform to the structure of the adjacent gneiss wherever observations in the French Creek and Hopewell mines and at intermediate exposures were made. In other words, there is no extensive cross-cutting of the gneiss by the diabase. From this it is inferred that the intruding magma accommodated itself in conformity with the pre-existing structure of the gneiss which it intruded. Since the gneiss is weaker in directions parallel to the banding than in directions normal to it, it is to be expected that the diabase would tend to mold itself in the former direction.

Westward from the Hopewell mines, though no observations can be made to confirm the actual relations, it appears that the diabase cuts across the structure. At least this seems to be true in the case of the Cambrian quartzites which farther south strike parallel to Welsh Mountain. It is possible, however, that the underlying gneiss diverges in strike from the later formation and that even here its structure is broadly conformable to the gneiss-diabase contact.

In the French Creek mine, the diabase shows both parallel and cross-cutting relations to the gneiss whose resistance to intrusion in each direction is well illustrated. Where the intrusion is normal to the foliation the resistant power of the gneiss in this direction was equal to or greater than that of the diabase magma impinging against it so that no injection took place and the contact is sharply defined and regular. In other places the gneiss has been intricately intruded by diabase tongues and dikelets. This relation is well developed in the cross-cut from the shaft on the 550 level of the mine shown in the cross-section, Figure 3. Here the gneiss has been so thoroughly intersected by diabase that angular blocks of gneiss are mixed together in a manner resembling a fault breccia. But there has been no slipping along the surfaces of the gneiss-blocks suggesting faulting, and no rounding of their edges to indicate replacement, thus showing that the phenomena is entirely due to intrusion and thrusting aside of the gneiss blocks by the greater force of the diabase magma which in this case has exerted its intrusive force parallel to the banding of the gneiss. In a similar manner, the dikes of diabase have intruded the limestone prior to its replacement by ore solutions, as will be shown later.

DESCRIPTION OF THE ROCKS

BIOTITE GNEISS

This gneiss is typically a banded rock with alternating light gray to pink and dark gray bands from a quarter to half an inch thick, and is composed essentially of orthoclase, quartz, mica, and graphite. The banding is in places very regular and distinct, and when the rock weathers this feature is accentuated because the lighter colored layers decompose more readily than the interleaved darker layers, causing them to stand out prominently. Commonly, their thickness varies gradually with coincident pinching out of the one or a merging of it into the bordering lighter or darker band. A distinct cleavage takes place between and parallel to the foliation. Such cleavage surfaces show glistening flakes of mica and often much pyrite in films and spherulitic aggregates or euhedral crystals.

From this typical phase there is considerable variation. The lighter bands may contain porphyroblasts of quartz and feldspar or auge-like masses consisting of a mixture of the two; or they may thicken out into such broad bands of fine-grained quartz and feldspar as to resemble a quartzite. The darker bands may also thicken to several inches wide, forming dense dark layers in which fine flakes of mica

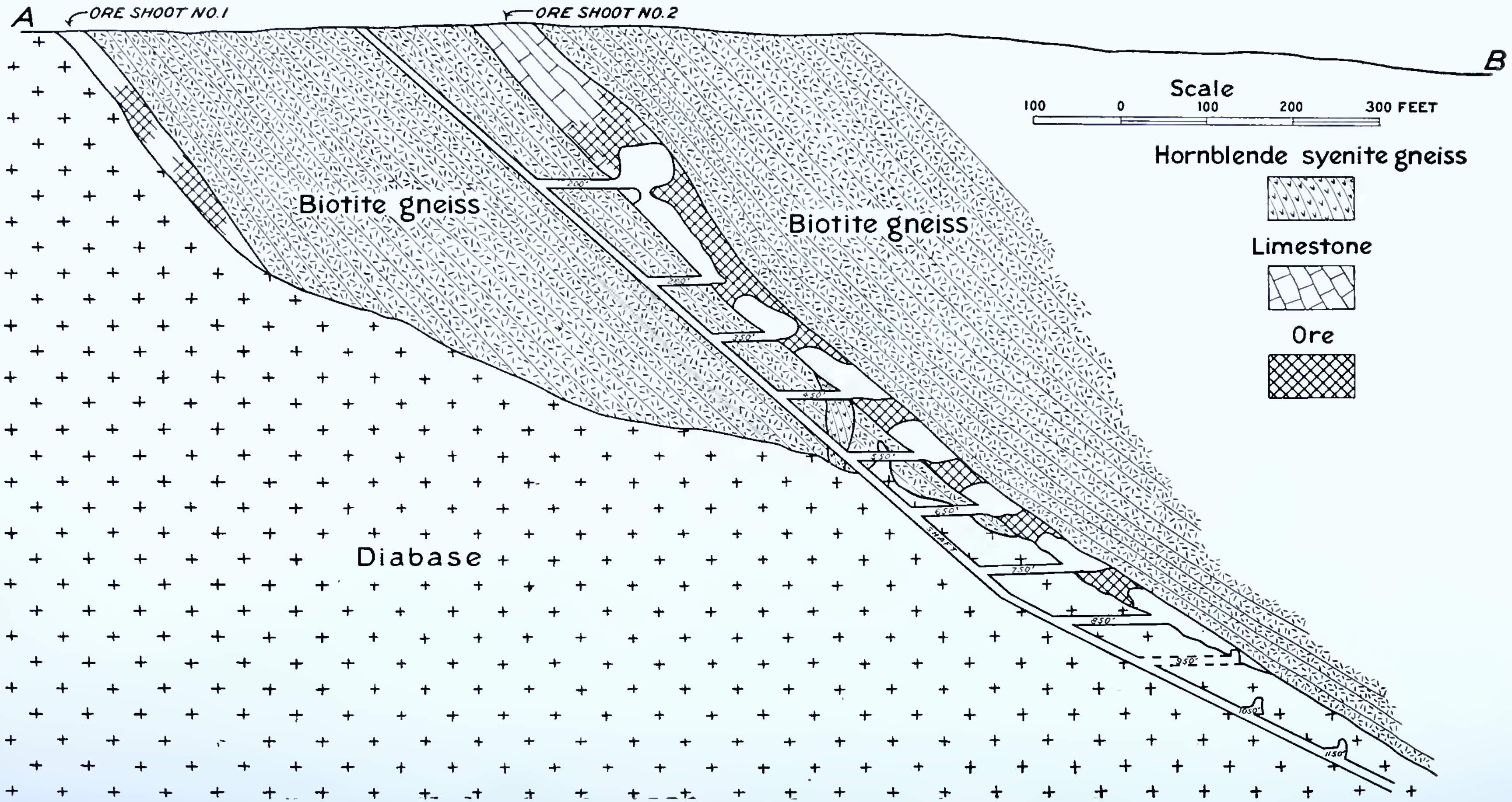


Figure 3. Geologic cross section of west end of French Creek mine.

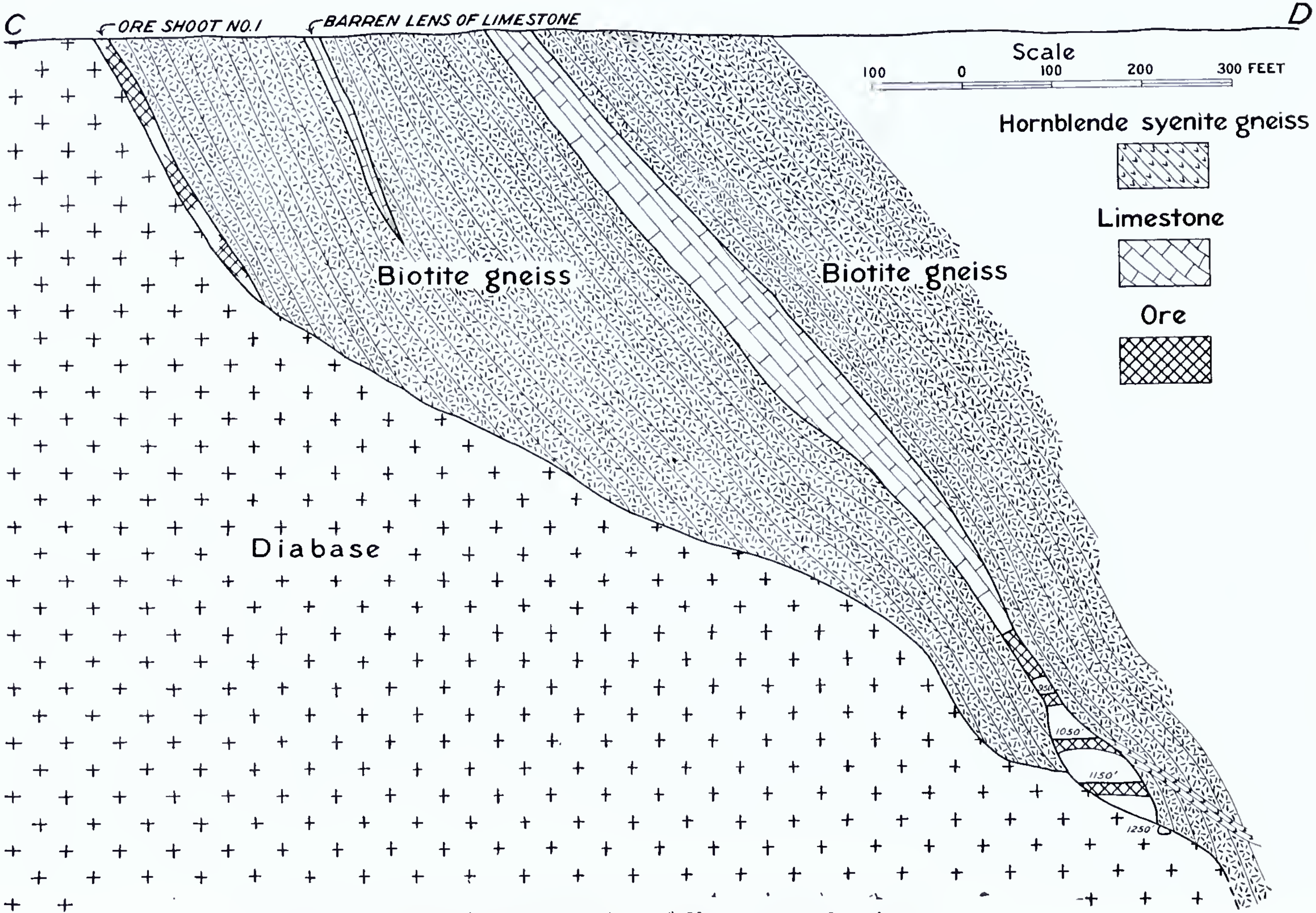


Figure 4. Geologic cross section of French Creek mine.

constitute the greater portion. Again, the narrow uniform bands may merge into nests of coarsely crystalline phases in which pink and gray feldspars and quartz are the main constituents with interspersed large glistening plates of mica.

The graphite, usually conspicuously present in the hand specimen in the form of small flakes parallel to the banding, may constitute such a large portion of the rock as to obscure the dense granular groundmass of quartz, feldspar, and mica.

The feldspar and quartz, with feldspar slightly predominant, are the principal constituents of the gneiss. They are commonly intergrown with suture-like boundaries not unlike those in a granitic texture; however, there is a tendency toward a lenticular development of the quartz areas especially where the feldspar is in excess and forms a groundmass for the quartz augen.

The feldspar is always clouded in appearance, most of it being orthoclase with noticeable quantities of perthite and occasional laths of acid plagioclase. The quartz frequently shows undulatory extinctions. It is often much fractured and sometimes poikilitically intergrown with the feldspar.

Under the microscope the mica is seen to be less abundant than one would expect. It never composes more than 20 per cent of the rock, even in the darkest bands. It is very fresh in appearance and pleochroic in light yellow to brownish red or reddish brown colors. The individual flakes have an average length of .5 mm. They are usually very perfectly oriented with their longer axes parallel to the foliation and their concentration in certain layers produces the banded appearance of the rock.

Graphite occurs interleaved with the mica in long lamellae or distributed through the quartz and feldspar groundmass but is always oriented parallel to the structure of the rock.

Pyrite frequently occurs in stringers interleaved with the mica in much the same manner as does the graphite. It is also abundant in large patches, slightly elongated in the direction of foliation, and distributed similarly to the mica and graphite. Some octahedral and pentagonal dodecahedral faces have been developed. Besides the above occurrences of pyrite which are believed to be primary, there is considerable pyrite distributed in streaks which cut across the structure of the rock. This and the megascopically visible films in the fractures of the rock are taken to represent introduced sulphide.

Limonite occurs sparsely distributed throughout the gneiss, and also very commonly as a border around the pyrite.

Apatite is always present in rounded grains or elongated prismatic sections with rounded ends. Zircon is also sometimes present occurring similar to the apatite.

Along several intersecting series of joints in the rock, shearing is evidenced by the displacement of the bands from a fraction of an inch to an inch. The joints are usually thoroughly healed by fillings of pyrite and chlorite.

Transitional phases from the typical gneiss to crystalline limestone were found in which there are varying amounts of calcite mixed and interlocked with the other rock constituents, either in well distributed grains or aggregated in small masses showing distinct rhombohedral cleavage. The distribution of calcite always conforms to the foliation of the rock, so that where it occurs in small amounts one would not suspect its presence upon superficial examination. These phases which occur along the contact with limestone or ore which the gneiss encloses, are always much altered, pyrite, chlorite, and actinolite being present as secondary minerals. This rock breaks easily owing to the weakness of the included calcite crystals.

Even when the contact between the typical gneiss and limestone or ore is sharply defined, the effect of contact metamorphism may be seen. The biotite in places has entirely decomposed into epidote and magnetite, with smaller amounts of hydromica and chlorite; or it simply may be bleached with the development of clusters and lines of magnetite grains through it. The feldspar is everywhere much clouded with the formation of chlorite. Chlorite also fills the rock fractures and cracks between crushed quartz grains. Reddish brown garnet is also a common constituent of these contact phases of the gneiss.

CRYSTALLINE LIMESTONE

This limestone is nowhere seen outcropping in the region but it is encountered in the mine, and its relations to the surrounding formations can here be clearly determined. What is generally seen is a very coarsely crystalline calcite in great masses, especially in the upper mine levels, where it may extend from footwall to hanging wall. This grades into a very even granular limestone whose outstanding characteristic is the presence of numerous disseminated flakes of graphite. This limestone where purest has a white to gray color and the shining graphite flakes give it a very striking appearance.

The texture is even granular with individual crystals from 2 to 3 milimeters across. There is commonly present a distinct lamination which is accentuated where partial replacement by ore has taken place. This banding is always parallel in strike and dip to the strike and dip of the gneiss. The twinning lamellae are commonly bent, showing the existence of residual strain effects subsequent to the crystallization of the limestone.

The very purest specimens of limestone contain besides graphite, small amounts of various minerals, though to what extent these represent original constituents or have been later introduced can seldom be determined.

Apatite in occasional rounded grains together with scattered grains of quartz are primary in origin.

Light green pyroxene is probably the most abundant foreign mineral constituent. It occurs in scattered flakes with roughly rounded outlines conforming to the boundaries of the surrounding calcite crystals, or it may be entirely included in a single calcite crystal. Such occurrences represent original impurities recrystallized at the same time as the lime sediments. Much of the pyroxene also occurs in aggregates or in parallel streaks where the calcite has been granulated. These seem to represent previous minute fractures or lines of weakness in the limestone. In such occurrences there is a tendency toward prismatic growth of the pyroxene. The prisms often cut across crystals of calcite, or larger patches of pyroxene may completely surround calcite individuals, thus suggesting its secondary introduction after the crystallization of the limestone.

Small limonitic particles, bright red flakes of hematite, and pyrite in grains and subhedral crystals have a sparing distribution.

ORIGIN OF THE BIOTITE GNEISS

The assemblage of evidence leaves little reason to doubt the sedimentary origin of this gneiss. It is believed to represent a metamorphosed clay sediment which has been consolidated and crystallized under mechanical pressure at intermediate depths. The distinct, persistent, and often very regular banding would then represent vertical variations in the composition of the original materials. Horizontal differences in composition along the bedding are reflected in the merging of the bands into each other.

The sedimentary origin is suggested by the presence of orthoclase, quartz, and biotite as practically the sole constituents. The accessory minerals with the exception of graphite and pyrite compose a very inconsiderable portion of the unaltered rock. The total absence of hornblende or any other minerals common to igneous rocks together with the even distribution of pyrite in such large quantities for a rock of this composition is also suggestive.

The high percentage of graphite generally evenly distributed throughout the gneiss but often so abundant as to form a graphitic schist, and its similar distribution in the inclosed limestone, is particularly suggestive of sedimentary origin. The presence of graphite is considered by most petrographers to represent the metamorphosed residue from the carbonaceous matter of the sediments.

The relation of the gneiss to the inclosed limestone lenses adds further evidence for belief in their sedimentary origin. There is a general parallelism in direction of strike and dip between the textural foliation, i. e., the orientation of the mineral layers, and the banding of the gneiss. And these are in conformation with similar textures and structures in the limestone, which warrants the belief that they came to their present state of crystallinity and have received their present form by a single common period of deformation. The contact between the gneiss and limestone also conforms in direction to that of the texture and structure.

Furthermore, the phases of gneiss found near the contact on both the hanging wall and footwall, in which calcite occurred in varying amounts interbanded and thoroughly interlocking with the constituents of the normal gneiss, seem to show conclusively that these are transition phases between the gneiss and limestone, and that the gneiss is also of sedimentary origin.

This series is undoubtedly pre-Cambrian in age. Anna I. Jonas[1] and E. T. Wherry[2] have described similar gneisses and associated limestones in the vicinity of Boyertown. They correlate the limestone with the Franklin of New Jersey, and the gneiss with similar pre-Cambrian sedimentary gneisses associated with the Franklin formation of northern New Jersey.

HORNBLENDE SYENITE GNEISS AND ASSOCIATED PEGMATITE

A dark massive to thinly foliated rock consisting essentially of hornblende and feldspar was encountered in the mine cutting across the banding of the biotite gneiss. Closely associated with the syenite gneiss is a coarsely crystalline pink to grayish green pegmatite. This formation will be described in considerable detail because of its seemingly apparent genetic relation to the ore.

This rock in its more massive phases might easily be mistaken for the diabase, but close examination shows that it contains a higher percentage of dark constituents which are megascopically black in color rather than dark green as in the diabase. It also shows no tendency to break with conchoidal fracture. The more gneissoid phases contain considerable pyrite distributed parallel to the foliation. The more massive phases contain no pyrite except in the numerous intersecting fractures which are filled with sulphide. The two structural phases may be entirely alike mineralogically, but usually the foliated rock contains more accessory minerals. The essential minerals which may practically compose the entire rock are orthoclase and hornblende. The accessories are microcline, plagioclase, biotite, quartz, apatite, epidote, garnet, chlorite, magnetite, and pyrite, all of which except microcline, plagioclase and apatite have a tendency to be more abundant in the banded phases.

The hornblende occurs as greenish yellow to greenish brown prismatic crystals about two millimeters in length. It shows all gradations from very fresh crystals to secondary epidote and magnetite. Alteration may take place along the crystal borders forming a bleached out jagged edge with the development of a peripheral fringe of magnetite grains (See plate IV, C). Or it may take place along the cleavage lines with development of a trellis-like structure incident upon the formation of lines of minute magnetite grains. Magnetite also occurs in rounded or lobe-like areas which, upon examination with the high power lens, prove to be bunches of smaller grains so thickly clustered together as to appear as one single solid grain. The magnetite increases in amount in proportion to the alteration of the hornblende. It appears to be always secondary in origin.

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[1] Jonas, A. I., Bull. Amer. Mus. Nat. History, vol. 37, 1917.
[2] Wherry, E. T., Bull. Geol. Soc. Am., vol. 29, 1918, p. 375.

A little microcline and acid plagioclase are usually associated with the orthoclase. Considerable quantities of biotite and lesser amounts of epidote are present in the banded phases. The biotite may be in the form of large fresh light yellow to chestnut brown individuals, or it may consist of an aggregate of smaller flakes intermixed with epidote in which case probably both minerals are secondary after hornblende. The large crystals are themselves in places altered to epidote and magnetite.

Some sections showed considerable quantities of an almost colorless garnet. Little rounded reddish brown garnets surrounded by haloes resembling kelyphite rims are occasionally enclosed in hornblende. They may be secondary after hornblende, or they may represent primary garnet which has developed the rims through near-surface alteration.

Quartz occurs sparingly in scattered grains, but more frequently it forms a poikilitic intergrowth with the biotite and garnet as hosts. Micropegmatitic intergrowths are also common especially near the contact of the syenitic rock with the pegmatite. Here also the quartz is much more abundant in scattered crystals thus suggesting the pegmatitic tendency of the intrusive.

Apatite in subhedral crystals has a rather uniform distribution and some chlorite is present in the altered rock where it forms a fringe around the hornblende from which it has developed by alteration.

Pegmatite associated with the hornblende syenite gneiss is so interbanded with it as to make their contemporaneity of origin indisputable. There is a gradual transition from the gneiss into the pegmatite through a decrease in the hornblende and an increase in the feldspar until the rock consists entirely of intermixed pink and gray feldspar and quartz and possesses a typical pegmatitic texture. The feldspar crystals average about 6 millimeters in diameter. The color of the rock may be bright pink, pale green, or it may be mottled pink and green due to the varying proportions of orthoclase and perthite. Numerous joints intersect the pegmatite. These are continuous into the syenitic rock and some of these joints have been filled with reddish brown garnets and chlorite.

Where the pegmatite cuts across the ore the contact is very irregular. Small stringers branch out through the ore and unreplaced calcite. Small patches of calcite also occur engulfed in masses of fresh pegmatite. See Plate V, C and D. Greenish yellow garnets, chlorite, and actinolite are particularly abundant as secondary minerals aggregated about these calcite inclusions. The sequence of these minerals in such cases is garnet, actinolite, and chlorite. These minerals also occur distributed through the feldspar of the pegmatite especially at the contact with the ore, where it is often more or less altered.

Pyrite has a sparing distribution as grains scattered throughout the rock, and especially around the calcite inclusions where the pyrite together with the magnetite are developed in euhedral crystals replacing the calcite.

The quartz areas are usually much crushed and calcite always acts as a filling in the fractures. It has apparently replaced some of the quartz. See plate V, D.

A little apatite is always present in the pegmatite. Epidote is a secondary mineral along the contact with the ore. Some graphite also occurs near the contact, having been picked up from the limestone.

At the Hopewell mine specimens of gneiss and pegmatite entirely similar to those at the French Creek mine were found on the dumps. Usually the rock here shows more complete alteration to epidote. Chlorite, actinolite, hydromica, and garnet are common in the more altered phases near the contact with ore, and are especially thickly aggregated about inclusions of calcite.

The hornblende syenite gneiss occurs abundantly only on the 450-foot level of the mine. Here the foliation is parallel to the structure of the mica gneiss and enclosed limestone and ore body. In the cross-cut from the shaft to the ore body on this level, the more massive phase with interbanded pegmatite was seen cutting diagonally across the structure of the mica gneiss, with the development of a fine-grained border phase in the former. Clearly enough the syenite and the pegmatite are complementary phases of the same intrusive which is later than the mica gneiss and limestones, but probably of pre-Cambrian age.

The foliated phase could not be traced directly into the more massive syenite but, since it possesses the same mineralogical composition and specimens from the dump showed all intermediate gradations, it undoubtedly represents portions which have had this structure secondarily induced by pressure. The foliation agrees in strike and dip with that of the mica gneiss so that it appears to have been produced by the same stresses. The lack of contact silicates in specimens showing the contact of the pegmatite and limestone indicates that the pegmatite was a relatively dry differentiate and had little metamorphosing effect upon the intruded limestone. The chlorite, actinolite, garnet, and other secondary minerals are believed to have been introduced later.

The hornblende syenite gneiss is again encountered in the four lower levels of the mine. In the western ends of the 1050 and 1150-foot levels it forms the hanging wall of the ore body, and again on the 1250-foot level, the ore terminates against this rock. Here the western end of this drift was continued through the gneiss which was found to be about 2 feet thick. Beyond it occurs a great mass of limestone which is unaltered except for the presence of a zone of chloritic material or byssolite between the intrusive and the limestone.

The hornblende syenite gneiss occurring on these lower levels is apparently a single intrusive dike which on the two lowest levels cuts diagonally across the structure and limestone lens, and on the 1050 and 1150-foot levels its course changes to one parallel to and between the biotite gneiss and included limestone body. Further discussion of the relation of this intrusive to the ore body is reserved to a later chapter.

CAMBRIAN QUARTZITE

The formation mapped as Cambrian quartzite overlies the crest and flanks of the Welsh Mountain anticline and extends from this point southwestward. Subordinate areas are cut off from the main mass by the western end of the diabase. These areas form the summits of prominent hills northeast of Welsh Mountain. This formation varies from a dense crystalline quartzite through more sandy phases to a micaceous gneiss or schist, and some phases are locally ferruginous. It is extremely resistant to erosion, especially the more quartzitic facies. P. Frazer[1] has mapped it as Potsdam and Primal sandstone and slate. To the southwest Bliss and Jonas[2] have correlated similar series with the Chickies, the Hardyston quartzite of New Jersey, and the Setters quartzite of Maryland.

CAMBRO-ORDOVICIAN LIMESTONE

In the extreme western portion of the area mapped, there is shown a strip of limestone lying above the quartzite and cutting it off from the Triassic shales to the northwest. This area is continuous down the valley of Conestoga Creek with the Cambro-Ordovician limestone which underlies the Lancaster and York valleys. It probably extends farther northward and eastward beneath the Mesozoic shales as it was found underlying them in the Jones and Warwick mines. This limestone is generally massive, bluish gray to dove-colored and apparently quite dolomitic. In the vicinity of Morgantown it has been extensively quarried for road material and also burned for agricultural purposes. At the Jones and Warwick mines this limestone has become the host for the ore body by being replaced by solutions from the underlying diabase.

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[1] Second Geol. Survey Pa., vol. C4.
[2] Bliss, E. F., and Jonas, A. I., U. S. Geol. Survey Prof. Paper 98, 1916.

TRIASSIC SANDSTONE AND SHALES

Judging from the surface fragments the Triassic formation in this area is largely a pea conglomerate of rounded quartz pebbles with intermixed finer sandy material, all thoroughly cemented together and possessing a reddish or brownish to gray color. Some of the pebbles are several inches in diameter, and may be either rounded or angular fragments of limestone, gneiss or quartzite. At Knauertown and eastward, near the north bank of French Creek exposures of soft deep red shale may be seen apparently lying directly on the gneiss. These beds represent the lowest horizon of the Triassic series.

In the exposures just south of the diabase quarry at Saint Peters, along the highway leading to Knauertown, is a stratigraphically higher succession of extremely dense, fine-grained, purplish to yellowish gray beds with a few interstratified coarser, more loosely cemented beds. The coarser beds consist of quartz and arkosic sands cemented by a buff to red clay, giving the rock a similar color.

The fine grained dense strata exposed at this point for about 500 feet are shaly Triassic beds which have been metamorphosed into hornfels by the contact action of the intrusive diabase. For a mile east and west of this point the contact is indicated by surface rocks of this resistant border facies. When the color is bluish gray it is difficult to distinguish this rock from the fine-grained contact phase of the diabase. The shale however breaks with a very smooth surface parallel to one plane, and it also does not weather by spheroidal spalling so characteristic of the diabase.

This indurated shale is composed chiefly of quartz with lesser amounts of orthoclase and an occasional plagioclase crystal. Chlorite and muscovite often form an irregular mesh about the quartz and feldspar. Flakes of greenish biotite are altering to muscovite, chlorite and magnetite. Magnetite and some pyrite are also plentiful in larger grains and euhedral crystals. Epidote may be abundant in small grains and some reddish garnets are usually present.

The coarser grained interstratified beds, above mentioned, have not been effected by contact metamorphism to any appreciable extent.

It is very difficult to distinguish between a vitreous phase of the Triassic formation and certain phases of the Lower Cambrian quartzites, some of which undoubtedly have been reworked and redeposited as Triassic sediments. The larger area here mapped entirely as Triassic may include some of the Cambrian.

PLATE II.

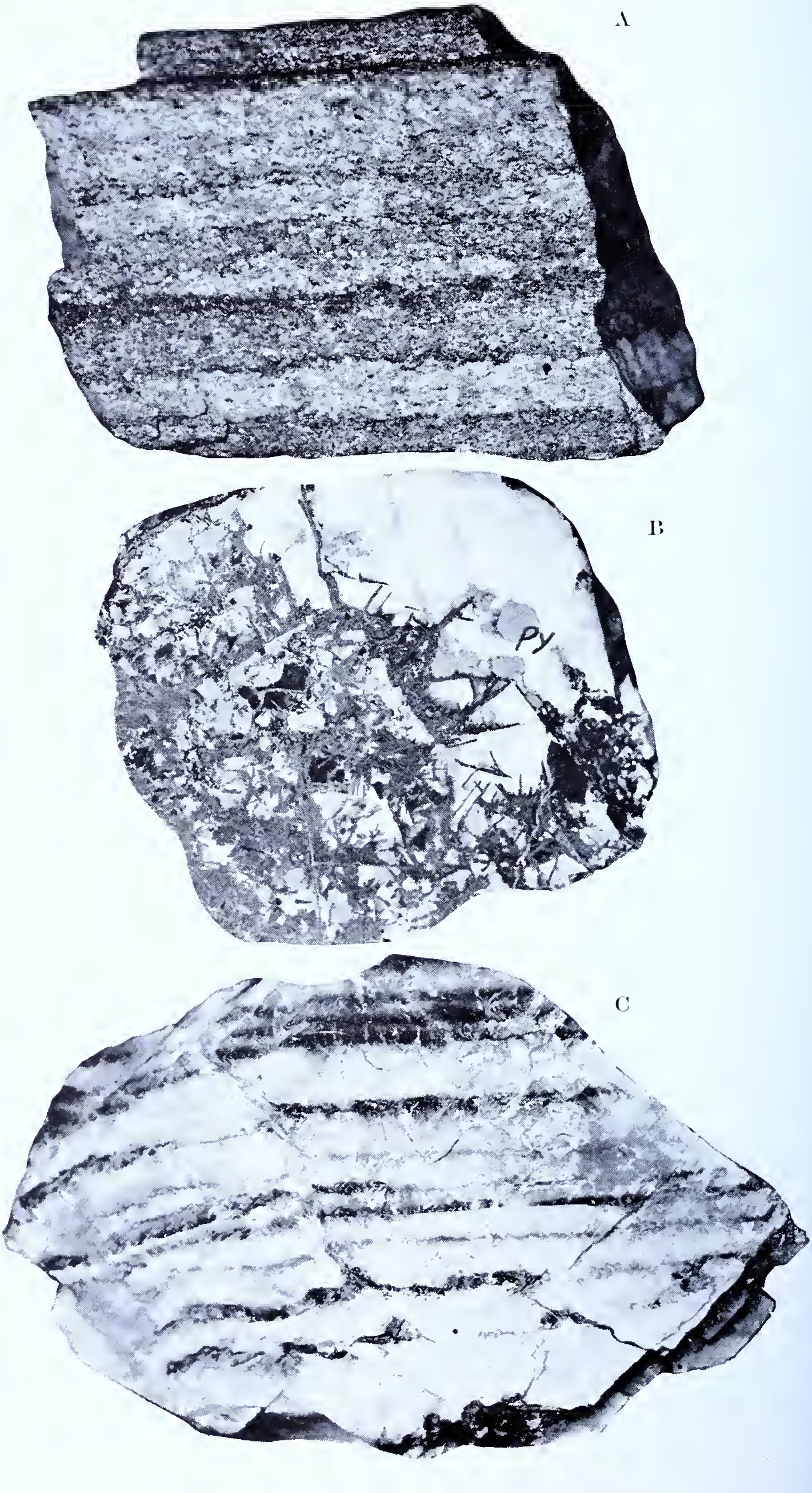

PLATE II

A. Photograph of sedimentary biotite gneiss showing typical banded structure. Natural size.

B. Photograph showing replacement of coarse calcite by ore. Note the development of platy structure and the tendency of the pyrite (py) to form farther into the calcite. Natural size.

C. Photograph of calcite rhomb. The banded appearance is due to replacement by chlorite along the twinning planes. Natural size.

PLATE III.

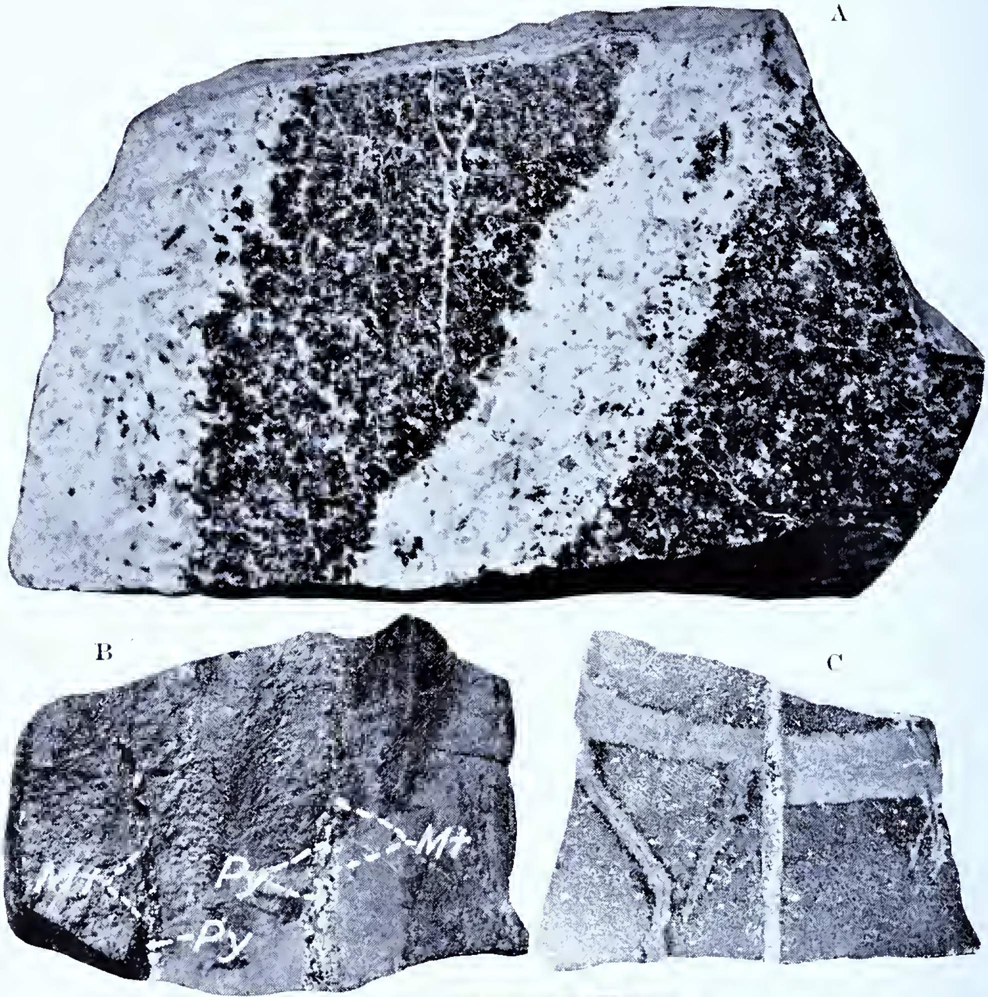

PLATE III

A. Photograph of diabase, cut by pegmatite dikes. Natural size.

B. Photograph of propylitized contact phase of diabase showing contraction fractures containing magnetite and pyrite. The magnetite (mt) has grown out from the walls of the fracture with some well-formed faces directed inward. Pyrite (py) was later deposited between the layers of magnetite. Natural size.

C. Photograph of polished section of contact phase of diabase showing healed fractures intersected by a later fracture (light). The later fracture has been filled with chlorite and pyrite. Natural size.

D. Photograph showing sharp contact of ore and crystalline limestone. Note the tabular structure of the magnetite, due to replacement along cleavage planes. Some of the plates are bent and curved. Natural size.

PLATE IV.

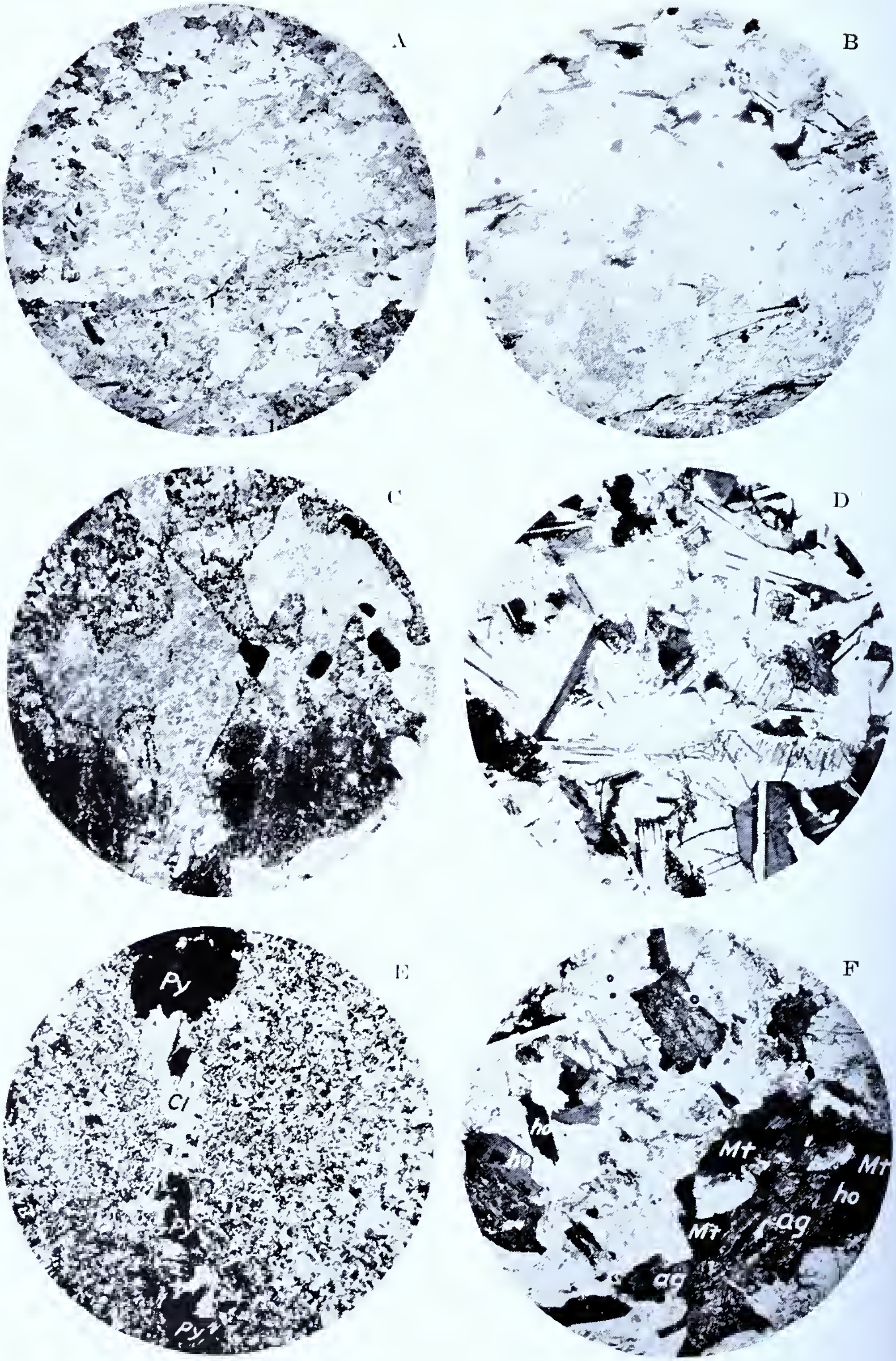

PLATE IV

A. Photomicrograph of typical biotite gneiss showing parallel arrangement of mica (gray flakes) with interleaved pyrite and graphite (black), and elongated quartz areas (white). The gray areas are feldspar which is clouded by alteration. Taken with plane polarized light. Magnification X 3.7.

B. Photomicrograph similar to A showing a portion of one band predominantly quartz and the other predominantly orthoclase. Pyrite has been introduced in the crushed mica flake in lower portion of field. The flake just above is interleaved with graphite. Taken with plane polarized light. Magnification X 5.

C. Photomicrograph of hornblende synite gneiss showing alteration of hornblende to epidote and magnetite. The light gray cloudy areas are orthoclase and the clear grains are apatite. Taken with plane polarized light. Magnification X 15.

D. Photomicrograph of section of diabase. Note the pinacoidal twinning of augite. Taken with crossed nicols. Magnification X 15.

E. Photomicrograph of propylitized contact phase of diabase intersected by small veinlet containing chlorite (cl) and pyrite (py). Magnification X 12.5.

F. Photomicrograph of segregation phase of diabase showing excessive magnetite and formation of hornblende (ho) and chlorite from augite (ag). Taken with plane polarized light. Magnification X 5.

PLATE V.

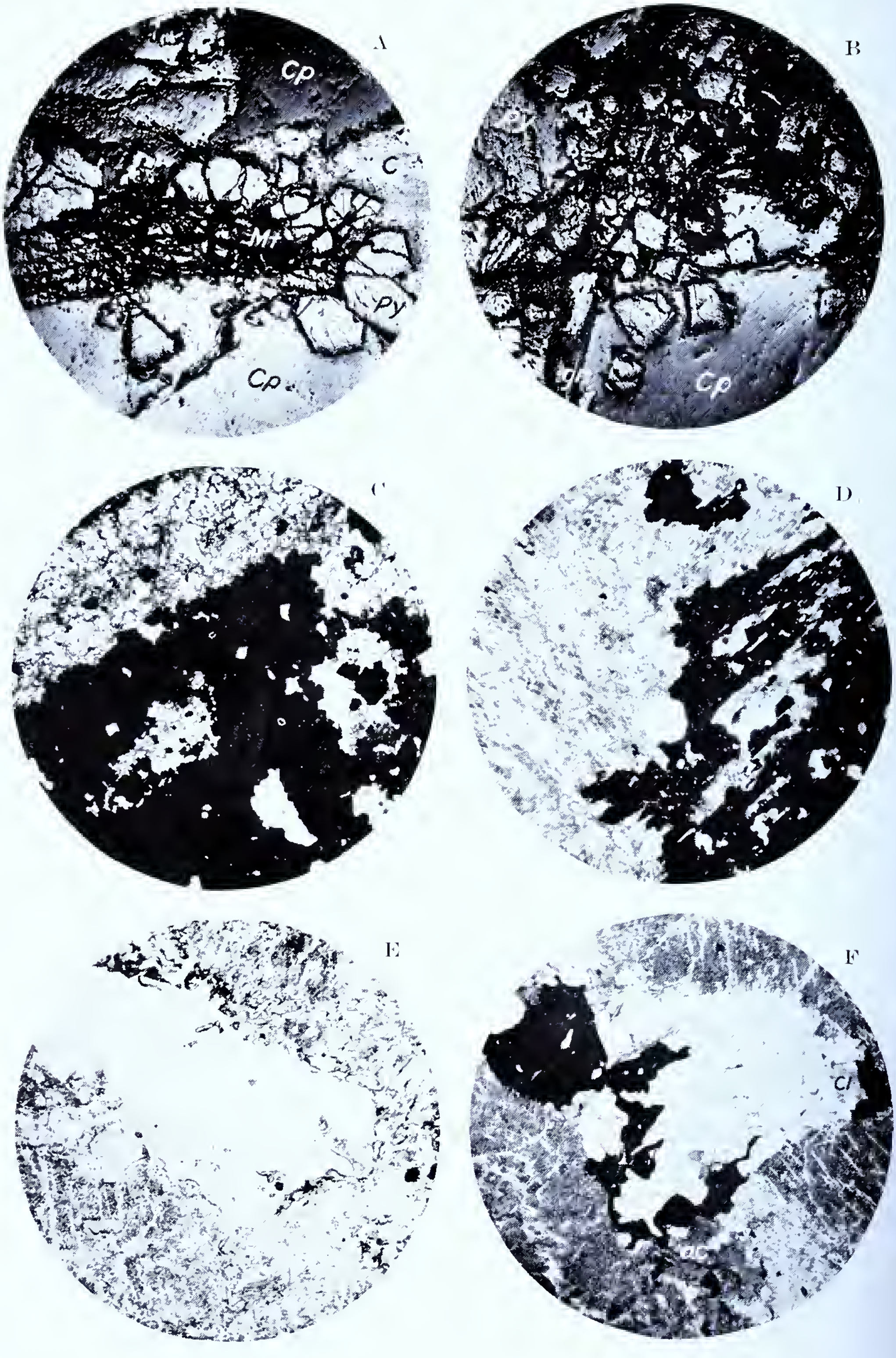

PLATE V

A. Photomicrograph of polished section showing euhedral crystals of pyrite (py) surrounded by chalcopyrite (cp) of a later generation. A bent and broken plate of magnetite (mt) with its crevices partially filled by later pyrite is shown in center of field. Some unreplaced calcite (c) in upper portion of field. Magnification X 14.

B. Photomicrograph of polished section similar to A. The long gray slivers in lower left field are graphite (gr). The black areas consist of calcite and magnetite not well differentiated. Magnification X 14.

C. Photomicrograph of thin section showing ore replacing epidote in altered hornblende syenite gneiss. The clear areas in lower portion of field are holes. Taken with plane polarized light. Magnification X 15.

D. Photomicrograph of thin section showing ore replacing feldspar of the pegmatite. The feldspar is clouded by the formation of chlorite and actinolite. Clear areas are holes in slide. Taken with plane polarized light. Magnification X 15.

E. Photomicrograph of calcite inclusion in pegmatite totally surrounded by feldspar. Garnet, actinolite, and chlorite occur around the calcite. Taken with plane polarized light. Magnification X 15.

F. Photomicrograph showing crushed crystal of quartz in pegmatite. The quartz (white) surrounded by altered feldspar (gray) is partially replaced along the fractures by calcite which in turn is partially replaced by actinolite (ac), chlorite (cl), and magnetite (black). Taken with plane polarized light. Magnification X 17.5.

The soft lower shales have been considered by Wherry[1] to be correlative with the Stockton or Lower Triassic of New Jersey.

DIABASE

The diabase exhibits no natural exposures but its extent is clearly delineated by the distribution of rectangular and rounded surface boulders. At Saint Peters this rock is extensively quarried by the French Creek Granite Company. and worked into monumental stone and paving blocks which are sold under the trade name of "Belgian blocks." There are three prominent systems of joints in this quarry, one horizontal and two vertical systems which intersect each other approximately at right angles. A third vertical set running transverse to these is commonly present together with numerous other less prominent and less persistent joints. A conchoidal jointing is also often exhibited and this causes considerable difficulty in blasting out the rock.

The rectangular surface blocks eventually become rounded because of the tendency for the rock to weather by spalling. Other phenomena peculiar to this diabase are the development of hexagonal surface cracks and the formation of boulder fields or "ringing rocks." A description and explanation of these phenomena as exhibited in this region has been given by E. T. Wherry[2].

Superficially, the diabase appears as a dark gray rock with medium fine-grained texture and possessing a tendency to break with a conchoidal feature. It presents a very regularly mottled appearance due to a uniform intermixture of green and light gray porcelaneous minerals.

Under the microscope these two principal constituents are seen to be augite and plagioclase which are present in approximately equal quantities. The feldspars are developed in lath-shaped interlacing crystals and the augite in general fills the irregular interstices between them, producing what may be termed an intergranular texture[3]. There is a disposition also for the feldspar and augite to be aggregated in alternating bunches in which either constituent may be relatively more abundant. In the areas where the aguite is in excess it, instead of being an interstitial filling, becomes a groundmass in which the feldspar laths are embedded and the texture then becomes ophitic.

The elongated plagioclase individuals seldom display crystal outlines. They abut against one another so that terminal planes are usually lacking. The larger crystals have a length of 1.5 millimeters and a width of 0.3 of a millimeter, but the greater portion of the laths are only about one third as large.

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[1] Wherry, E. T., Proc. Phila. Acad. Nat. Science, vol. 64, 1912, p. 169; vol. 65, 1913, p. 114.

[2] Wherry, E. T., Proc. Phila. Acad. Nat. Science, vol. 64, 1912, p. 169.

[3] Professor Kemp in his "Handbook of Rocks," has used the term "diabasic" to apply to such textures where the augite and other mafic minerals fill the triangular spaces between the more abundant feldspar laths. It was later similarly used by J. Volney Lewis in describing the diabases of New Jersey in "Petrography of the Newark Igneous Rocks of New Jersey," Annual Report N. J. Geol. Survey, 1907, p. 109. The term seems to be aptly applied especially since such textures have more than a casual occurrence.

The maximum extinction angles are 26°, corresponding to acid plagioclase.

In the normal diabase, the plagioclase presents a very fresh appearance. Twinning after the pericline and Carlsbad laws is frequent in addition to the common albite type.

Sometimes the augite forms elongated crystals as much as 2 milimeters in length. The color is pale green and absorption in different shades of green can be recognized.

Two kinds of pinacoidal twinning are commonly present; often both occur in the same individual, the one parallel to the orthopinacoid (100) producing paired halves, the other parallel to the basal pinacoid (001) giving exceedingly minute thin lamellae. The maximum extinction angles are 40°.

Slight alteration is quite generally apparent. This takes place either along the pinacoidal cleavage cracks or between the multiple twinning lamellae, with the production of very minute grains of magnetite which are often so numerous as to give the crystals a dusty appearance under the miscroscope. Besides this secondary occurrence, magnetite also appears in sparsely scattered subhedral and irregularly shaped grains, which have crystallized before the augite but later than the feldspar. It constitutes about one-half of one percent of the rock.

Pleochroic yellowish-brown to chestnut-brown biotites occur in scattered flakes and as borders around the magnetite, or as secondary fringes around the augite. Chlorite occurs similarly to the biotite.

Near the margin of the diabase the texture becomes finer. In the mine this decrease in size of grain becomes noticeable along the crosscuts from the shaft to the ore body, within 10 or 12 feet of the contact with the ore. But where the diabase is in contact with gneiss, a variation in texture may not be detected until within 4 or 5 feet of the contact. Presumably, the limestone has a lower specific heat than the gneiss, permitting a more rapid dissipation of the heat of the magma along its contact, with the resultant finer grain. This variation in size of grain is so constant that it serves as a safe criterion in determining the proximity of the ore body when drifting or drilling to locate its position.

In this finer textured diabase the augite is often developed in two generations. There is an earlier formation of relatively large crystals contemporaneous with or before the plagioclase, and a second development of smaller crystals filling the angular spaces between the feldspar. The augite quite generally has a pale greenish-yellow appearance with correspondingly lower interference colors.

The plagioclase may occur in fresh rather poorly developed laths or it may be quite uniformly altered throughout the whole section into a confusing aggregate of fringed, low doubly-refracting scales.

There is a considerable increase in the proportion of biotite present both as scattered flakes of primary origin and as secondary fringes around the augite. The biotite borders around the magnetite are also more pronounced. Grains of magnetite may be entirely surrounded by relatively large rims of chestnut brown biotite, in which case they are probably coronas in the sense that Sederholm has used the term to designate the formation of secondary rims by reactions during crystallization, but primary in the sense that their development was prior to the consolidation of the magma.

Chlorite is also more abundant in the fine-grained diabase. It forms radiating fibrous aggregates or large light green, often fan-like flakes, all secondary after augite. The joints, especially in the finer grained facies of diabase, are filled with thin films of chlorite.

The texture passes from micro-diabasic or micro-ophitic to micro-granitic, the feldspars loose their elongated shapes, and twinning lamellae and are seldom discernable in the very dense border phases. It is only by a determination with index solutions that the true character of the feldspar can be established. The indices of refraction were found to range from 1.560 to 1.540, thus corresponding to an acid plagioclase or oligoclase.

Immediately at the contact and within a few inches of the ore, the rock becomes trappoid and its composition shows the result of contact action of the ore solutions. It possesses a purplish-gray to greenish color and shatters easily into irregular splintery fragments. The surfaces of the fractures along which it breaks have a dark green color and a shining lustre. The dike-like masses of trap rock in the ore have a similar nature. They, however, show evidences of some shearing and along these surfaces chloritic material has been formed. The minerals composing these dense phases are feldspar, biotite, zoisite, epidote, magnetite, and a little pyrite. Occasional remnants of augite can be distinguished. The magnetite is in the form of very minute, thickly distributed grains. There is an abundance of well-developed, elongated prisms of zoisite in the feldspar.

The biotite, chlorite, and epidote have a tendency to occur in aggregates, and their association with remnants of augite indicates their secondary nature.

The metamorphism has involved no transfer of constituents other than water and a little sulphur, and the process is entirely similar to that of propylitization.

The border facies of diabase is frequently intersected by numerous little veinlets or healed fractures filled by coarser minerals of predominantly light color. These veinlets are composed of orthoclase, plagioclase, quartz, mica, chlorite, augite, magnetite, and pyrite. They grade into the normal surrounding rock through a decrease in size of grain and a decrease in quartz, orthoclase, and chlorite. The phenomenon is explained by the shrinkage and cracking of the earlier chilled periphery while the interior of the magma was still molten. This permits the migration of other magma material into these fractures, and, since the surrounding rock is now uniformly heated to a higher temperature, a coarser texture results. These intruded materials would have a higher silica and vapor content, which would result in the more acid nature of the veinlets and the formation of chlorite and mica and less augite.

Later peripheral fractures were accessable only to the solutions which caused the propylitization of the contact. Into these have been deposited magnetite, pyrite, and minerals associated with the ore, especially chlorite. See plates IV, D, and E.

Of peculiar interest is a type of coarse-grained, light colored diabase which was recovered from the mine dump. These phases form tabular segregations in the normal rock from ½ to 3 or 4 inches wide and appear to intersect it much as do the joints. In most cases a shearing surface was found intersecting them.

The most striking thing regarding this phase of the diabase is the presence of long blades of dark minerals which, megascopically, appear to cut across the lighter constituents. Upon breaking the rock with a hammer these tabular dark blades break out readily and are found to be highly magnetic. Pyrite in small quantities can also be seen with the unaided eye.

Microscopically this rock differs from the adjacent diabase into which it grades by having a greater amount of feldspar, and by the development of the dark minerals in unusually long laths or prisms which seem to have crystallized simultaneously with the plagioclase. The laths of plagioclase are often over 4 milimeters in length. In places they present a peculiar dusty aspect, and are usually much clouded by alteration. The usual twinning according to the albite, pericline, and Carlsbad laws is present. The plagioclase crystals may grade outward into micrographic intergrowths with quartz and frequently such intergrowths compose the greater portion of the rock. Poikilitic intergrowths of plagioclase in pyroxene as host are also frequent.

The augite prisms are sometimes over 4 millimeters in length and often terminated by faces. The typical twins and prismatic cleavage are conspicuously present, and the crystals have the peculiar dusty aspect seen in some of the plagioclase.

Hornblende occurs in large yellowish brown to seal brown prisms, and also in ragged shreds scattered through the augite. The secondary nature of the hornblende after augite is apparent. The hornblende prisms are frequently bent and broken.

Magnetite constitutes as much as 4 or 5 per cent of the rock. The individual grains are very large and are almost always closely associated with hornblende. See plate IV, F.

Chlorite and biotite are present in considerable amounts as secondary minerals.

There are also large amounts of apatite in extremely long narrow prisms from 0.018 to 0.016 milimeters across and from 0.5 to 1 milimeter in length.

The explanation of the origin of this phase of diabase is probably similar to that of the veinlets occurring along the periphery. They seem to represent a tendency toward segregation along early developed joints and planes of weakness in the cooling magma. These places of weakness collected excessive amounts of mineralizers which upset the normal order of crystallization and also resulted in the formation of hornblende, biotite, chlorite, and magnetite at the expense of augite. Later they still continued to be planes of weakness and further jointing and slipping took place along them. This is evidenced by the shearing surfaces, bent hornblende blades, and poikilitic textures.

PEGMATITE DIKES IN DIABASE

In the lower levels of the mine, the diabase is intersected at intervals by pegmatite dikes 1 to 3 inches in width, which cut across the drifts at various angles but each individual dike has quite a regular strike and dip. From the main dikes smaller ones branch out and end in sharp angles. See plate III, A.

These dikes are composed essentially of plagioclase which is somewhat coarser in texture than that of the normal diabase. The crystals also are quite generally clouded by alteration. Considerable augite is mixed with the plagioclase. Probably most of it was picked up from the walls of the dike. The augite is to a large extent altered to hornblende and chlorite.

Quartz, apatite, magnetite, pyrite, and chalcopyrite comprise the remaining constituents. Magnetite and pyrite tend to form in large octahedral crystals, while the chalcopyrite occurs in smaller irregular grains. Any casual fragment of this pegmatite, if powdered, heated with hydrochloric acid, and treated with ammonia will give a positive reaction for copper.

These dikes have their position and extent determined by contraction fissures which tapped deeper reservoirs of the diabase magma, from which more acid and more volatile constituents were extruded. The contacts are not sharply defined due to the effect of the more fluid pegmatitic magma and the still highly heated condition of the surrounding wall rock.

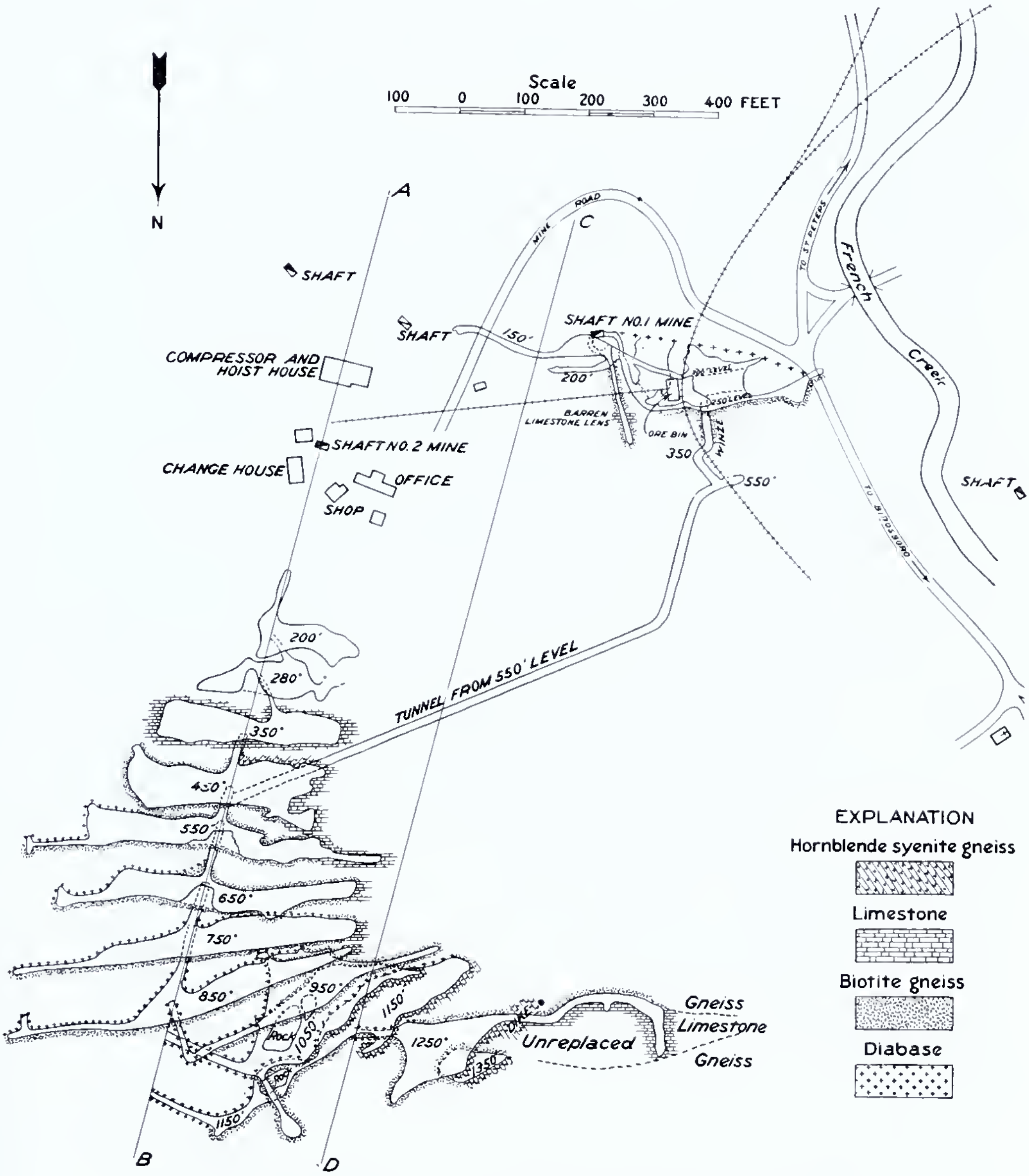

Figure 5. Plan of workings, French Creek mines

FORM, SIZE, AND STRUCTURE OF THE ORE BODY

The ore body is the result of replacement of a limestone which is a member of the pre-Cambrian sedimentary series now metamorphosed into gneiss, and interstratified crystalline limestone, and calicite. Thus the ore shoot corresponds in direction of strike and dip to that of the limestone which is also in conformity with the enclosing gneiss. Reference to the map (Figure 5) on which the plan of the mine has been projected on a horizontal plane will give a general conception of the extent of the workings.

The large ore body on which mine No. 2 was developed has an average slope length of 40 to 50 feet, a breadth of about 450 feet, and has been developed for a distance of 1700 feet along its length. The average strike of the ore body is nearly east and west, the dip 45°, and pitch 17° east of north. On the 950-foot level the strike changes to N. 75-80°E, the dip flattens out to 35 to 40° in the east end of this level but steepens to 60° in the west end, while the pitch at this point turns suddenly to the west as will be noted on the plan map.

This mine was formerly worked by a vertical shaft down to the 200- or 280-foot levels and then the present shaft was driven with a slope of 43°, from which crosscuts on the various levels were made to the ore body. This shaft was expected to finally intersect the ore body in depth but below the 750-foot level it was found that the ore shoot was flattening out to such an extent that it would be necessary to change the angle of slope from 43 to 33°. The cross-section, Figure 3, which was constructed along the line A-B of the plan map, shows this change of dip in the ore body and the consequently necessary change in the angle of slope of the shaft in developing the mine. The cross-section constructed along C-D on Figure 4 shows the reverse condition in the west end of the mine below the 750-foot level. The dip is here steeper with a consequent change in strike.

The hanging wall is formed by the gneiss throughout the whole extent of the ore body and it is notably regular in both strike and dip. Were it not for the unreplaced masses of limestone this feature would be still more marked. Where the limestone has been totally replaced the ore lies directly under the gneiss, and their contact conforms to the strike and dip of the very regularly banded gneiss.

The footwall is more undulating and especially is this true below the 550-foot level where the diabase forms part of the footwall of the ore body. The eastern end of the ore shoot finally pinches out by the diabase coming in contact with the gneiss hanging wall. This diabase-ore contact is characteristically rolling in contrast to the regular gneiss-ore contact. The pinching out of the ore body on the eastern ends from the 850-foot level downward causes it to pitch strongly to the west carrying the ore shoot farther away from the diabase intrusive. Finally on the two lower levels the gneiss again forms both the footwall and hanging walls. The ore body here entirely pinches out in depth; and westward along its strike, it ends abruptly against a wall formed by a 2-foot dike of hornblende syenite gneiss on the 1250-foot level. A drift was run for nearly 200 feet westward beyond this dike, but it encountered only finely crystalline unreplaced limestone. Prospect drilling along this drift showed that the gneiss country rock forms both hanging and footwalls. The diabase is over 100 feet below the footwall of gneiss, and the limestone pinches out in depth before encountering the diabase. The only remaining channel by which solutions from the diabase could reach this limestone mass would have been from the east end, but here the lens is cut off by the above mentioned dike. Thus this portion of the limestone being well sealed from solutions emanating from the diabase is entirely unreplaced by ore and also has retained its finer crystalline texture.

The thickness of the limestone included between the gneiss, or gneiss and diabase, is quite invariable especially in the upper levels. The irregularities in thickness of the resultant ore shoot are caused principally by masses of unreplaced limestone. In the east end of the 750-foot level there is a constriction of the walls downward till in the 950-foot level this portion of the ore shoot is entirely absent. On this level it will also be noticed that the ore body becomes forked into two branches. These enclose a "horse" of fine-grained diabase much sheared and mixed with the limestone and ore.

The mine map includes the plan of the No. 1 mine which has been worked to a depth of 250 feet. The "gophering" method of mining followed in developing this deposit is depicted on the mine plan, the irregularities of which are not due so much to the inconsistencies of the ore body as they are to the unsystematic methods pursued in leveloping it. This mine has long been abandoned and its condition prevented a thorough investigation, though enough observations were made to show its similiarity to the larger deposit. The general strike of the hanging wall, which is always gneiss, conforms very closely to that of No. 2 mine. Its dip however is in general somewhat steeper, being about 65° N. The footwall of the ore shoot is formed by diabase except in the extreme west and where it is in contact with gneiss. This ore-diabase contact is also characteristically undulating as noted above in the case of No. 2 mine.

Eastward along the direction of strike of this ore shoot are two old shafts and several obscured pits which evidently mark the extension of the ore in this direction.

A drift between the 150- and 200-foot levels, running almost directly north and south, cuts across gneiss nearly at right angles to the strike of its banding for the entire length of the drift, with the exception of several feet of fine crystalline limestone occurring interstratified with the gneiss. The abandoned shaft west of French Creek may be located on a mineralized portion of this limestone lens, but more probably it is it is on the westward extension of the No. 1 ore body.

The tunnel shown on the map connecting the 550-foot level of the No. 2 with the No. 1 mine cuts diagonally across the structure of the biotite gneiss country rock, but encountered neither ore nor interstratified limestone layers.

The character of the association of ore and limestone as seen in No. 2 mine is largely dependent upon the crystallinity of the limestone. Where the limestone is fine to medium-grained and compact as commonly found immediately adjacent to the footwall or hanging wall or at the west faces of the drifts, the ore ends abruptly and has sharply defined contacts with the limestone, or at most sends but small stringers out through the cleavage of the limestone. But most of the limestone has been recrystallized into coarsely crystalline calcite which is crushed and fractured, thus effecting an irregular system of channels for the circulation of ore solutions with a consequent irregular distribution of masses of ore and intervening masses of calcite, except where total replacement has taken place. In the lower levels complete replacement has been more nearly effected, while in the upper levels the masses of calcite increase till above the 200-foot level where the ore body ends in coarse calcite. A similar condition is met in the west ends of the drifts except here the ore more often ends in the finer crystalline limestone. There tends to be more complete replacement in the narrower portions of the ore shoot, especially on the 750- and 850-foot levels. In the broader portions masses of calcite are more frequently encountered.

The ore occurs as masses of magnetite with intervening masses of comparatively pure limestone, or the limestone may be entirely replaced from footwall to hanging wall by ore. In either instance the limestone will exhibit scattered pockets or stringers of magnetite, and the ore will contain disseminated remnants of crystals of calcite.

The ore body is shattered and intricately intersected by joints and faults of small displacement, neither of which manifest any especially favored direction of strike or dip. All variations from vertical to horizontal dips occur and quite commonly the joints are of conchoidal shape. The sheared and sliken-sided surfaces in limestone are wavy and coated with chlorite; in the ore they are smoother and lustrous. Some of these joints and slicken-sided surfaces end with the limits of the ore body while others are continuous from the ore into the diabase.

Masses of dense fine-grained diabase occur at places as angular blocks or "horses" in the ore. Where little shattered the true relations of this diabase can be determined. It undoubtedly represents dikes from the main intrusion which have cut across the limestone to the gneiss hanging wall. and have suffered shearing subsequent to ore deposition thus mixing angular blocks of the diabase with ore and limestone. These diabase "horses" occur only below the levels where gneiss forms the footwall.

It is interesting to note that the Hopewell deposit apparently bears a similar relation to the gneiss and diabase intrusion. Examination of the dumps revealed specimens that were exact duplicates of types occurring at French Creek. There are two abandoned mines about 400 yards apart and each located at the contact of the gneiss and the diabase intrusive. The one mine was worked by a shaft to a depth of 200 feet, the other mine to the southeast consists of an open-cut 600 feet long and 60 feet deep. The writer was informed that in each case the ore body was underlain by diabase while the hanging wall consisted of gneiss. The average dip of the ore body was 30° N.W. and the strike in each was N.61°E. A line connecting these two deposits has the same strike and along this line are located several pits that formerly yielded ore. It will be noted that the strike of the ore deposit corresponds in direction to the strike of the contact between the diabase and gneiss.

CHARACTER OF THE ORE

The ore mineral is magnetite, with which is associated large quantities of pyrite, some chalcopyrite, and varying quantities of lime-iron silicates as gangue. Calcite, of course, is the principal gangue constituent, and at places considerable quantities of diabase are mixed through the ore.

The magnetite ranges in texture from dense massive to coarsely granular. The coarser grained type tends to be more common in the upper levels, where it replaces the coarse calcite and where large masses of calcite remain unreplaced, while the finer granular or dense massive ore is more common in the lower levels where almost total replacement is more commonly met with, or in places where the ore has replaced a finely-crystalline limestone. See plates II, B and III, D.

The dense ore may be very hard and compact but usually there is enough included calcite or its metamorphosed products to make it crumbly. All the ore disintegrates rapidly when exposed to the atmosphere, presumably due to the oxidation of the pyrite and the resultant effect of the sulphate so formed upon the carbonate gangue.

The crystalline magnetite occurs in octahedrons with bright surfaces, frequently in combination with rhombic dodecohedral faces, but well formed crystals are uncommon and are found only along contacts with calcite or as linings of vugs and cavities.

A peculiar feature of the magnetite is its tabular to micaceous texture. The flat surfaces of the plates exhibit a brilliant shining lustre. The individuals may be perfectly straight and parallel or they may be curved and bent, often into peculiar fan-like aggregates. Again a triangular development may be seen. See plates II.B and III.D. This tabular structure is clearly due to the replacement of the calcite along its cleavages, which have formed directions of least resistance to the penetrating solutions.

The gangue minerals named in the probable order of their abundance are calcite, chlorite, pyrite, actinolite, talc, hydromica, garnet, epidote, graphite, augite, chalcopyrite, pyrrhotite, and apatite. Of these calcite, graphite, and apatite represent original unreplaced constituents of the limestone. This is true also of part of the pyrite and augite.

Large masses of a greenish soapy micaceous material called byssolite occur with the magnetite and also as irregular sheets along fractures intersecting the calcite and some distance from locii of mineralization. These foliated masses are soft when taken from the mine but become hard upon exposure. They are composed principally of chlorite with lesser amounts of talc and hydromica. The foliae are often cut across by stringers and plates of pyrite, thus showing their earlier deposition in the period of mineralization.

The replacement of calcite commonly takes place along the cleavage with a rounding of the rhombohedral angles, but frequently there is also replacement along the twinning planes, especially by chlorite, illustrated in plate II, C.

Actinolite occurs in the ore as acicular fibres or felty aggregates, and frequently large masses of nearly pure actinolite are met with. These masses like the ore, contain a rather constant proportion of disseminated graphite and apatite. Chlorite and its common associates, talc and hydromica, are found everywhere in the ore.

Garnet and epidote are found only in small quantities and are usually detected only in thin sections. The garnet is of a faint red to pale yellowish-brown color but appears yellowish-green in thin section. From its high alumina and calcium and low iron content it is clased as the variety grossularite. The garnet is surrounded by birefringent rims of epidote, and from this association and other features it appears that the epidote is largely secondary after the garnet.

Augite is present in only small quantities, and much of this was an original constituent of the limestone.

Pyrite always constitutes a large proportion of the ore. Beautiful euhedral crystals of pyrite are common in the coarser crystalline ore. The most common form is the octahedron, this being frequently modified by rhombic dodecahedron and cube faces. The various crystal forms of pyrite from this locality have been carefully described by S. L. Penfield[1].

Some chalcopyrite is always present in the ore. Euhedral crystals are of very infrequent occurrence. Some of the chalcopyrite, especially in the upper levels, has oxidized to malchite and azurite. Undoubtedly the blue and green stains from these carbonates first led to the opening of this mine for copper, but the percentage of copper in the ore has never been high enough to warrant its extraction.

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[1] Penfield, S. L., Pyrite from French Creek. Amer. Jour. Sci., vol. 37, 1889, p. 209.

The following chemical analyses of the ore, ranging over a period of seven years, were furnished by the mine superintendent, Mr. Hoster, and are published with his consent. They represent the analyses of average specimens of ore for the respective years.

Analyses of magnetite ore from French Creek mine, Saint Peters, Pa.

	Fe	SiO_2	Al_2O_3	CaO	MgO	P	Mn	S
8-27-14	53.45	10.30	1.91	4.39	1.26	.025	.16	2.42
3-14-16	54.40	8.38	1.33	3.28	1.88	.025	.11	3.10
3-5-18	57.78	7.10	1.37	3.44	1.41	.039	.12	2.94
3-5-19	56.98	7.46	1.36	3.32	1.26	.027	.10	2.82
2-12-20	52.73	12.95	2.50	4.13	1.70	.041	.15	2.60
5-6-21	51.78	13.51	2.76	4.70	2.18	.056	.14	2.45

The outstanding features of this ore from a chemical standpoint are its low phosphorus and high sulphur content. The percentage of phosphorus is well below the Bessemer limit, but this desirable quality is partially offset by the disadvantages of a high sulphur content which necessitates treatment of the ore by sintering in order to eliminate the excess sulphur before charging in the furnace. The high lime is advantageous but the combined lime and magnesia is not sufficient to offset the relatively high silica, so that some lime must be added for fluxing.

The lower iron and higher silica, alumina, lime, and magnesia shown in the analyses for the last two years is due both to the more compact nature of the ore and the higher percentage of gangue minerals in the lower levels. In the upper levels, the ore was less intimately mixed with limestone and consequently when blasted a natural mechanical separation from the calcite took place so that a higher grade of ore could be extracted without the expenditure of any extra labor. In the lower levels, where the gangue minerals and remnants of calcite tend to be more intimately mixed and disseminated through the ore, this separation is not possible.

PARAGENESIS

The silicate minerals as a group are of an earlier generation than the ore and sulphide minerals, but the genetic relations of the silicate minerals to one another are from their nature determined with difficulty.

The garnet is definitely earlier than the hydrous silicates, which have worked their way through the irregular cracks of the garnet, sometimes completely enclosing numerous little grains. Garnet, augite, and actinolite probably are nearly contemporaneous in time of formation, though some of the actinolite seems to show evidence of being a later mineral.

Epidote is usually found in close association with the garnet, and is largely a secondary alteration of this mineral. In plane polarized light they have about the same yellowish green color and are quite indistinguishable, but with crossed nicols the borders and cracks through the garnet are bi-refringent and the presence of grains of epidote mixed through and sorrounding crystals of garnet becomes unmistakable.

Chlorite, hydromica, and talc occur in large patches with branches penetrating the cracks of garnet and the cleavage of augite and epidote. Sheaf-like clusters of actinolite are enclosed by the hydrous silicates, and their frayed out ends merge into the surrounding minerals in such a way as to indicate the later formation of the chlorite, talc, and hydromica. These hydrous silicates, even though secondary after the calcium-magnesium-aluminus-iron silicates, are still in general the result of the work of magmatic solutions and should not be thought of as being entirely formed by secondary alteration processes which were operative subsequent to the period of mineralization. They indicate the instability of the first formed silicate minerals under the influence of later magmatic solutions of a different chemical composition and having a lower temperature. However, some of the hydrous silicates are undoubtedly secondary in the stricter sense and have been formed subsequent to ore deposition.

Apophyllite, though a mineral for which this deposit is noted, was not found in any of the sections examined. It occurs in fractures in the gneiss walls or in vugs in the ore, and its genetic relations were not determined. It is, however, considered to have been one of the last minerals formed as it is soluble in water at lower temperatures and pressures.

Magnetite is later than any of the above named silicates. It cuts across actinolite needles, fills cracks in garnet, and replaces and surrounds all the hydrous silicates. Some pyrite is earlier than the magnetite, but this is believed to represent the pyrite that was indigenous to the limestone, for usually the pyrite shows evidence of being later than the magnetite. The pyrite has migrated beyond the zone of deposition of magnetite. Along former loci of replacement of limestone by ore, pyrite is usually seen to have developed a few inches out in the limestone beyond the magnetite. See plate II, B. Where fractures have been available to act as adits, the pyrite has been carried much farther before being deposited. The fractures and foliation planes of the surrounding gneiss contain large quantities of introduced pyrite. In many cases, stringers of pyrite may be seen cutting across foliae and sheets of chlorite. Contraction fractures in the periphery of the diabase usually contain only pyrite, chlorite, and other hydrous silicates. But when magnetite is present its earlier generation than the pyrite is frequently clearly shown. See plate III. B.

Chalcopyrite is still later in generation than the pyrite. See plate V. A.

The paragenetic sequence may then be written as follows: 1. garnet and augite, 2. actinolite, 3. epidote, 4. chlorite, talc and hydromica, 5. magnetite, 6. pyrite, 7. chalcopyrite.

The hydrous silicate period of mineral deposition undoubtedly overlaps and probably continues beyond the periods that follow; and that of the pyrite may begin before and overlap the magnetite periods. Otherwise the periods seem to be quite closely defined and adhere to the sequence given.

ORIGIN AND GENESIS OF THE DEPOSIT

The details so far enumerated indicate that the ore is the result of replacement of lens-shaped bodies of limestone by solutions emanating from the diabase intrusion. The deposit was formed contemporaneous with the cooling and solidification of this intrusion. It could not well be earlier for at no place is the ore cut by the main body of the diabase. The fine-grained diabase dikes found in the ore were intruded before replacement took place, as is shown by their sheared nature which was occasioned by the later cooling and contraction through gravitative adjustment of the main intrusion. If the deposit is considered later than the diabase, it would be necessary to account for its strict association at the contact of the latter. Furthermore, the replacement took place before final consolidation and contraction was complete, as indicated by the presence of magnetite, pyrite, and gangue minerals in contraction joints along the periphery of the diabase.

The mine dumps indicate that coarse pegmatite in large masses, already described, was associated with the ore in the upper levels of the mine. This association suggests to the casual observer that there may be some genetic connection between the pegmatite and ore.

In the Hopewell mine, a similar pegmatite may be seen in the southwest end of the big open-cut working. Unfortunately the mine is nearly filled with water, and the sides of the open pit are obscured by debris, thus precluding observation. However the author was informed that this pegmatite formed a dike about 20 feet thick and ran diagonally across the ore body. This fact alone, of course, suggests that the pegmatite is later than the ore body, but further evidence shows that the intrusion of the pegmatite into the limestone was an earlier event, and that the mineralization of the surrounding limestone took place sometime after this intrusion.

It has been previously shown that this pegmatite and its complementary hornblende syenite gneiss phase is later than the sedimentary mica gneiss, and also it is believed to be of Pre-Cambrian age. At least it is older than the ore body and diabase intrusion, though this could not be directly observed for the diabase and pegmatite were not found in contact. The banded structure of the gneissoid phase and the crushed quartz grains similar to such phenomena in the biotite gneiss suggest that this formation is older than the diabase and has been subjected to earlier mechanical stresses.

If the little garnets and their associated haloes are correctly interpreted as kelyphitic rims then it appears that this rock was a deep-seated intrusive which was later altered under near-surface conditions. This is furthermore conclusively shown by the complete alteration in some instances of the hornblende of the gneiss to epidote and magnetite. Sections along the contact with the ore show that the epidote has been later replaced by ore. The orthoclase of the pegmatite has been similarly replaced. See plate V, C and D.

The ore solutions also had a contact effect in causing the formation of the minerals garnet, actinolite, and chlorite along the borders of the hornblende-syenite gneiss. These minerals, which are common gangue silicates, have been similarly developed in contact phases of the biotite gneiss. Also, these minerals are abundant, particularly around the calcite inclusions where they were presumably deposited by penetrating ore solutions. See plate V, E. Such ore solutions would further account for the large quantities of pyrite which have been secondarily introduced into the fractures and between the foliae of the banded gneiss. In a similar manner the calcite which has replaced crushed quartz grains in the pegmatite is believed to have been carried and so deposited by calcic solutions escaping from the limestone body that was being replaced by ore. See plate V, F.

Further evidence that the hornblende syenite gneiss and pegmatite bear no genetic relation to the ore body is shown by the conditions found in the west end of the ore shoot on the 1250-foot level as described on a previous page. Here the ore body ends against a dike of hornblendic rock which is clearly a phase of the hornblende-syenite gneiss. The limestone was replaced by ore up to this dike, but beyond it on the western side and away from the diabase the limestone is entirely unreplaced and lacks the coarse crystalline texture so common where the limestone is in close proximity to the ore. This mass of limestone is so uncontaminated by silicate minerals and has been proven to be of such size, estimated at 2,000,000 tons, that the mining company seriously considered its extraction on a commercial scale.

If the ore solutions emanated from this dike of hornblendic rock or its related phases, there appears to be no reason why the limestone was replaced on one side of the dike and not on the other. However, if this and other similar dikes of hornblende syenite gneiss and pegmatite are taken to be incidental intrusions across the country rock and included limestone previous to ore deposition, the relations as found are as would be expected.

The facts seem to show conclusively that this hornblende syenite gneiss and its pegmatitic differentiate were intruded into the gneiss and limestone with little resultant metamorphic effect. Subsequent forces produced a foliation and fracturing. Later the diabase was intruded; ore bearing solutions from it replaced the limestone and also some of the altered hornblende syenite gneiss and pegmatite along their contacts; and they further deposited pyrite and silicate minerals in contraction fractures along the periphery of the diabase itself.

The ore solutions should not be supposed to have emanated from the upper periphery of the cooling diabase rock. If so it would be difficult to reconcile the fact that unreplaced portions of limestone often lie against the diabase.

The ore magma was a late stage differentiation product of the deeper diabase magmatic reservoir from which it was exuded. The inthrusting magma probably slightly lifted the overlying rock and some dikes cut across the limestone. Fissuring due to contraction and settling followed. But before this proceeded far, the ore magma solutions ascended along these channels and ore deposition began by replacement of the limestone. After the completion of ore deposition, there was further fracturing and shearing of the ore body as adjustment to gravitative forces continued.

These same fissures in the diabase which tapped the magma reservoir were thrust apart and intruded by acid differentiates forming the later pegmatite dikes already described. Other fissures formed early in the consolidation of the diabase magma became places of access for the collection and concentration of aqueous and gaseous components which were expelled from the solidifying magma. Along these fissures there was a tendency toward a concentration of the iron oxide and sulphide. These developed so early in the cooling magma that they became healed before final solidification and are now evidenced only by the coarser textured phase of diabase which has been described.

It has been noted that the only observable portions of the diabase which carry any pyrite or chalcopyrite are the more acid differentiates along these fissures; in fact, the chalcopyrite was found only in the pegmatites. Magnetite is distributed throughout the diabase as a rock constituent, and as such was a component of the rock magma. But the magnetite is also found in much greater abundance in the coarser diabase adjacent to fractures and in the pegmatite dikes. These concentrations are believed to have been precipitated from a later portion of the magma which contained a higher percentage of the magnetite components. This is entirely in harmony with modern conceptions of ore magmas as later differentiation products. Since the pegmatites are also late differentiates and formed nearer the period of the expulsion of the ore magma, it is to be expected that these pegmatites would be more likely to contain some of the metallic differentiates. This further leads to the conclusion that the ore solutions originating from greater depths in the magmatic reservoir came up through channels similar to those into which the pegmatites were intruded.

Because of the relatively low temperatures at which pyrite is precipitated, it stays in solution longer than magnetite and migrates beyond the zone of replacement. The temperature at which replacement of limestone by magnetite was taking place was still high enough to keep the pyrite in solution. These solutions penetrated the available crevices and fractures cut in the gneiss country rock, so that we now find considerable pyrite occurring as introduced sulphide in the fractured gneiss and some distance from the ore body. Magnetite is always precipiated before getting that far. In the ore body also, the pyrite may frequently be seen several inches out in the limestone in advance of the limestone-magnetite contact.

The assemblage of gangue minerals is typical of a contact metamorphic deposit formed at intermediate depths and at moderate temperatures. From the character of these silicate minerals, it is assumed that the ore magma was relatively basic and contained no excess silica beyond that necessary to unite with the iron, aluminum, calcium, and magnesium oxides, and, consequently, quartz does not occur as a gangue mineral. Such basic magmas have little contact effect upon the wall rock, and contain relatively little material in solution beyond the ore content.

Several analyses of specimens of apparently original unmineralized limestone were made. A comparison of such analyses with the analyses of the ore should manifestly give some idea of the character and amount of material added thru replacement of the limestone. But the inaccuracy of the values obtained by such a comparison was made evident by the fact that the limestone analyses showed a higher alumina content than the average alumina content of the ore. The inability to obtain specimens of limestone which one could be certain had received no addition of material from the ore solutions made such results unreliable. It, however, seems reasonable to conclude that besides the iron and copper, most of the alumina, silicon, sulphur, and manganese shown in the ore analyses were contributed by the ore magma. The calcium, magnesium, and phosphorus are entirely residual from the original limestone.

It is believed that the coarsely crystalline calcite associated with the ore is the result of the action of aqueous solutions or vapors and not due entirely to the heat of the intruding magma. That this marmorosis was previous to ore deposition and even preceded the deposition of the hydrous silicates is proven by the facts enumerated. See page 41. Yet the strict association of this calcite with the ore and the fact that the ore body ends along its westward strike in fine grained limestone indicates a similarity in origin. Protected and unfractured masses of limestone adjacent to the hanging-wall have also often escaped recrystallization. It appears that early formed fractures attendant upon intrusion or later contraction served as channels for the solutions and vapors which, together with heat, have effected the marmorosis before the deposition of gangue minerals and ore. The structure of the gneiss hanging-wall is furthermore favorable to this process by acting as a barrier in confining the solutions to the limestone. These solutions which produced the marmorosis and which were given off after intrusion and some fracturing had occurred are comparable to the ore magma from the standpoint of source, but differ from it in point of time and also content. The ore-bearing solutions were of a later generation and carried the metallic materials besides aqueous vapor.

The barren fine-grained limestone body shown in Figure 4 is believed to be lens-shaped and to die out at no great depth by a constriction of the walls of the enclosing gneiss. Hence, this limestone body is sealed off from the effect of solutions from the under-thrusting diabase. If this assumption be true it would explain why this body of limestone has escaped marmorosis and mineralization. The other two interstratified limestone horizons at French Creek and the similar one at the Hopewell mine have been cut by the diabase intrusion or at least the intrusion has come in contact with them, and as a result they have been exposed to the effect of solutions and vapors which produced recrystallization and later mineralization of the limestone. Unfortunately a dike which, as has already been explained, cut across the limestone of mine No. 2 on the 1250- and 1350-foot levels effectively sealed off a large portion of this limestone lens from solutions from the later diabase intrusive. These solutions might otherwise have replaced this limestone. We believe that an ore body will be found wherever there was a limestone to act as host and wherever this limestone was accessible to the mineralizing solutions from the diabase.

It is possible that further exploration along the contact of the diabase and gneiss may locate other limestone lenses which have received replacements by ore. With this thought in mind the E. & G. Brooke Iron Co. has attempted to locate additional ore by prospecting with the magnetometer along the northern contact of the diabase. This prospecting has been pursued as far west as the Hopewell mine (see geologic map) but so far without encouraging results.

RELATIONS TO THE CORNWALL TYPE OF DEPOSITS

A. C. Spencer[1] made a comprehensive report on the magnetite deposits of the so-called Cornwall type which occur in the Piedmont belt of southeastern Pennsylvania, and found that in all cases the ore deposits were intimately associated with intrusions of diabase. The ore occurs as replacements of calcareous strata belonging either to the Paleozoic No. 2 limestone of Rogers (Cambro-Ordovician), or to limestone conglomerate beds at the base of the Mesozoic. In fact a favored place of occurrence is at a horizon near the unconformity between the Paleozoic and over-lying Mesozoic strata. It was largely this constant association of ore and diabase which led Spencer and later Harder[2] in describing the deposits of the Dillsburg district to conclude that the diabase magma was the source of the iron solutions.

Spencer found that the intrusions were either dikes or sills of varying size. Since the sills occur mainly in the Mesozoic strata he concludes that they must have been fed by channels which traversed the Paleozoic basement rocks underneath. Indeed, outside the area of Mesozoic strata there occur truncated narrow dikes which he believes are of the type which acted as feeders to the sills.

Large bodies of ore were found to be more likely to occur near larger masses of diabase, and vertical cross-cutting intrusions were found to be more favorable than sills of low inclination. This association would be expected, since the ore solutions must certainly have come up through the same channels as the diabase, and since the dikes must be more directly connected with the deep magmatic reservoir than the sills.

Spencer finds only one circumstance adverse to the belief that both the water which effected the metamorphism of the Mesozoic shales along the contact of the diabase, and that from which the iron was deposited, were derived from the same intrusions; namely, the uncommonness of the deposits. "If certain of the intrusive masses furnished iron for large deposits, why is it that similar segregations do not occur in association with every important mass of diabase?" The writer is not prepared to answer this question, but offers the following suggestions: These iron-bearing solutions may have expended their ore content upon lower limestone horizons not discernable from surface observations. The occurrence of the French Creek deposit in pre-Cambrian limestone gives this suggestion credence. Here the solutions did not contain enough iron to replace the inclined limestone beds all the way to the present surface, and thus if Paleozoic limestones here overlaid these pre-Cambrian rocks certainly they would not contain deposits of ore at their contact with the diabase, for only solutions depleted in iron would reach them. Further if some large sills were fed by narrow dikes it is reasonable to suppose that these channels became sealed before the expulsion of ore solutions which we now know to be later differentiates. Thus there would be no accessible upward passageways of escape for the ore solutions, and the mere presence of diabase masses in contact with limestone at the surface would not necessarily preclude favorable conditions for an ore deposit. The diabase is so constant in composition wherever found that it seems reasonable to believe that where there is an intrusion of considerable size connecting directly in depth with the main magma and a replaceable limestone in contact with the intrusion, there should be an ore deposit.

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[1] Op. cit.

[2] Harder, E. C., Structure and origin of the magnetite deposits near Dillsburg, York County, Pa. Econ. Geol., vol. 5, 1910, pp. 599-622.

The assemblages of contact minerals in all the deposits described by Spencer are practically the same as those described in this paper. They are never developed in large quantities, and the unreplaced limestone forms the principal gangue as is the case at French Creek. Harder, however, notes that when very impure beds are replaced the gangue minerals are more abundant in quantity but still of the same typical varieties.

Another feature which all deposits of the Cornwall type have in common with the French Creek deposit is the high sulphide content. Many of them also carry a notable quantity of copper; especially is this true of the Cornwall mine where this element constitutes about 0.6% of the ore and is sufficient in quantity to pay the overhead expenses of operation.

The Jones mine, three miles west of the Hopewell mine, is an example of the Cornwall type. It will be seen from the geologic map that this mine is located along the northern margin of the same diabase intrusions as the French Creek and Hopewell mines. But the diabase is here in contact at the surface with Triassic red sandstones rather than gneisses.

The red sandstone near the mine is only 30 or 40 feet thick. Underlying it are limestone beds presumably of Cambro-Ordovician age. These limestones have been replaced by ore, practically all of which was extracted many years ago. The remaining beds of ore are too thin and too lean to work. The limestone host being rather impure, the ore was not as high grade as that at the French Creek mine.

Mining by open-cut was carried down to the diabase which is now found in the bottom of the open-cut workings at a depth of 100 feet. Recent drilling revealed several thin layers of lean ore interbedded with beds of impure limestone and soapstone, all dipping away from the diabase at a slight angle. Aside from the bedded nature of this ore body and the greater amount of gangue, both of which are due to the character of the limestone acting as host, this deposit is entirely similar to the French Creek type.

SUMMARY

The French Creek magnetite deposits are in every way similar to the Cornwall type, except in the character and age of the limestone which is replaced. They are replacements of lenses or tabular bodies of limestone interstratified with gneiss. This sedimentary series of gneiss and limestone, presumably of pre-Cambrian age, was first intruded by hornblende syenite with complementary pegmatite dikes which are also probably of pre-Cambrian age. These intrusions locally cut across the interstratified calcareous beds, but produced practically no metamorphic effects.

Sometime after the deposition of Lower Triassic shales, local intrusions by basic magmas took place. The position of these intrusions was to a certain extent governed by the pre-existing structures in the gneiss. These basic magmas solidified as diabases and were potentially the parent magmas of iron ore deposits. Where calcareous beds were favorably exposed to the effects of solutions emanating from greater depths in the cooling magma and late in the stage of cooling, replacement and mineralization resulted.